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the AGRO-CLIMATOLOGY of North Dakota

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part 2 / PRECIPITATION: FORECAST, PROBABILITIES AND RAINMAKING

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One of the variable resources which is of utmost importance to the economy of North Dakota is annual precipitation.

When fluctuations in time and amount of a variable such as precipitation occur within narrow limits, predictions may be made without great error and with comparative ease. As the magnitude of fluctuations increases, accuracy of predictions tends to decrease. Annual precipitation in North Dakota has varied widely over the years in both amount and the times during the year when it has occurred.

It is for this reason accurate predictions and forecasts for precipitation in North Dakota are complicated and difficult. However, with the aid of advanced knowledge, the use of extensive past weather records, and the capability of the computer, it is possible to develop information which gives a higher degree of confidence and accuracy to long-term predictions and forecasts for precipitation. This information at the disposal of the North Dakota farmer can provide him with better guidelines to be used in his practical judgement and management decisions.

This second publication of a planned series of four on North Dakota Agroclimatology deals specifically with precipitation. Dr. J. M. Ramirez and his colleagues have endeavored to reduce extensive records and analyses into a readable and useful publication intended to serve as a better basis of knowledge and understanding to be used in future planning than is presently available.

ARLON G. HAZEN, Director
Agricultural Experiment Station

THE AGROCLIMATOLOGY OF NORTH DAKOTA

Part II. Precipitation: Forecast, Probabilities and Rainmaking

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PART 2. PRECIPITATION: FORECAST, PROBABILITIES AND RAINMAKING

A. PRECIPITATION: NATURE AND INFLUENCES

Precipitation and Agriculture in North Dakota

Water is the most abundant, the most widely distributed and the most commonly used chemical compound on our planet Earth. It is an integral part of every living being and an essential component of fertile soil. Its scarcity, abundance or overabundance is often the difference between life and death.

The total water supply on the planet Earth is estimated at 326 million cubic miles, of which over 97% is in the oceans. Of the remaining total, the major portion is in the polar ice caps. Annually, North Dakota's supply, including an average precipitation of 17 inches and known water supplies on and below the soil surface, represents about 105 million acre-feet. This amounts to less than three cubic miles, an infinitesimal amount in relation to the total.

North Dakota's agriculture and general economy is closely linked to this most common of substances, so much so that water supply and distribution may serve as a barometer of the material welfare of its citizens. The major source of water for the production of its crops is natural precipitation. The precipitation which falls directly on that part of the land where crops are grown is by far the most important water source for crop production in the state.

This bulletin describes the past experiences in North Dakota with precipitation amounts, distribution and frequencies of occurrence. Properly used, these recorded experiences may be extrapolated into the future to serve as a guide in decision making for a wide spectrum of activities, especially in agricultural management and operations.

The Formation of Precipitation

Water Vapor in the Air

Water is probably the most variable constituent of our atmosphere. The amount of water in the air, in the form of gas, could theoretically range from nil to 5 per cent by volume near the ground. In reality, a value of 2 per cent constitutes very humid air, typical of the tropics and of summer weather on the Atlantic coast of the continental United States. Water vapor variability and its reversible transformation from gas to liquid (condensation), liquid to gas (evaporation) and gas to solid (sublimation) are two of the major reasons for the various weather changes occurring on our planet Earth.

As humid air is forced upward or is heated near the ground causing it to rise by buoyancy, it is subjected to lower air pressures and cooler temperatures in the higher levels of the atmosphere. This process cools the humid air to a point where it condenses to liquid (as water vapor in the air condenses to liquid on the outside of a glass of icewater). The condensed water vapor in the atmosphere forms what we see as clouds.

Growth of Clouds

The start of condensation at 100 per cent relative humidity is not a problem in our atmosphere because of the abundance of impurities such as tiny particles of salt, dust, and certain industrial products in the air. These particles, usually referred to by scientists as condensation nuclei, are necessary to provide the starting points for condensation as they attract water vapor to their surfaces forming droplets that we see collectively as clouds. These water droplets can persist and grow larger as more water vapor in the air condenses.

Raindrop Formation

The process involved in the growth of tiny cloud droplets to the size of raindrops has been difficult to fully understand. At the present time, two mechanisms have been proposed to explain the growth of cloud droplets to raindrops and ice crystals. The first mechanism involves the hypothesis that larger drops that form on larger particles of salt for instance, fall faster within the cloud than the smaller droplets, colliding with some of them and drawing others into their wake from the rear. One may visualize a similar process taking

place on the rain-wetted windshield of a car. The bigger drops may then grow to such a size that they cannot be supported by air anymore and thus fall as rain.

The second mechanism proposed is that some of the cloud droplets freeze into ice-crystals while some remain in the liquid form as supercooled water droplets at those altitudes where the temperatures are below freezing. When this combination exists in a cloud, the water droplets tend to evaporate and condense onto the ice crystals, forming larger crystals which eventually attain fall velocities. As they fall, they accumulate other small droplets in their way until they grow large enough to fall as raindrops.

The growth of cloud droplets into raindrop sizes usually means increasing the droplet size over 200 times to attain the conventional minimum raindrop size of ½-millimeter. This growth depends upon how much liquid water there is in the cloud and how far the drops can travel within it. This travel may be both upward and downward as what has been found to occur in updraft and downdraft currents within thunderclouds.

The natural cloud and precipitation processes require the presence of air impurities such as salts, dust, soot and combustion products. In its natural state, our atmosphere has been found to always contain certain amounts of these impurities available for cloud formation. Man and his activities have been adding contaminants to the air, both deliberately and inadvertently. These increasing levels of air pollutants have always been associated with their effects on man's health. However, it is also logical and possible that excessive air pollutants may affect the natural precipitation processes in our ocean of air.

Measurement of Precipitation

Precipitation amounts are measured in terms of the height of water that would accumulate over an impervious surface if run-off from its edges were prevented. Almost any type of collector will do, but standard rain gauges used by the National Weather Service have an 8-inch diameter receiver at the top. Rainwater flows from this exposed receiver to a collector through an opening which is very narrow to prevent evaporation. Where only a daily rainfall record is wanted, an ordinary stick calibrated in inches or millimeters is used to measure the height of water that has accumulated and the gauge is emptied for the next day's reading. In remote rain stations where daily observations and automatic recorders are not available, large containers are used to accumulate rainwater over a week, a month or even a season.

Weighing rain gauges (Figure 1) are available to give a more refined and continuous record of precipitation occurrences. Their records permit determination of intensity and duration of individual rain storms and thus provide an important set of data required in various rainfall analyses.

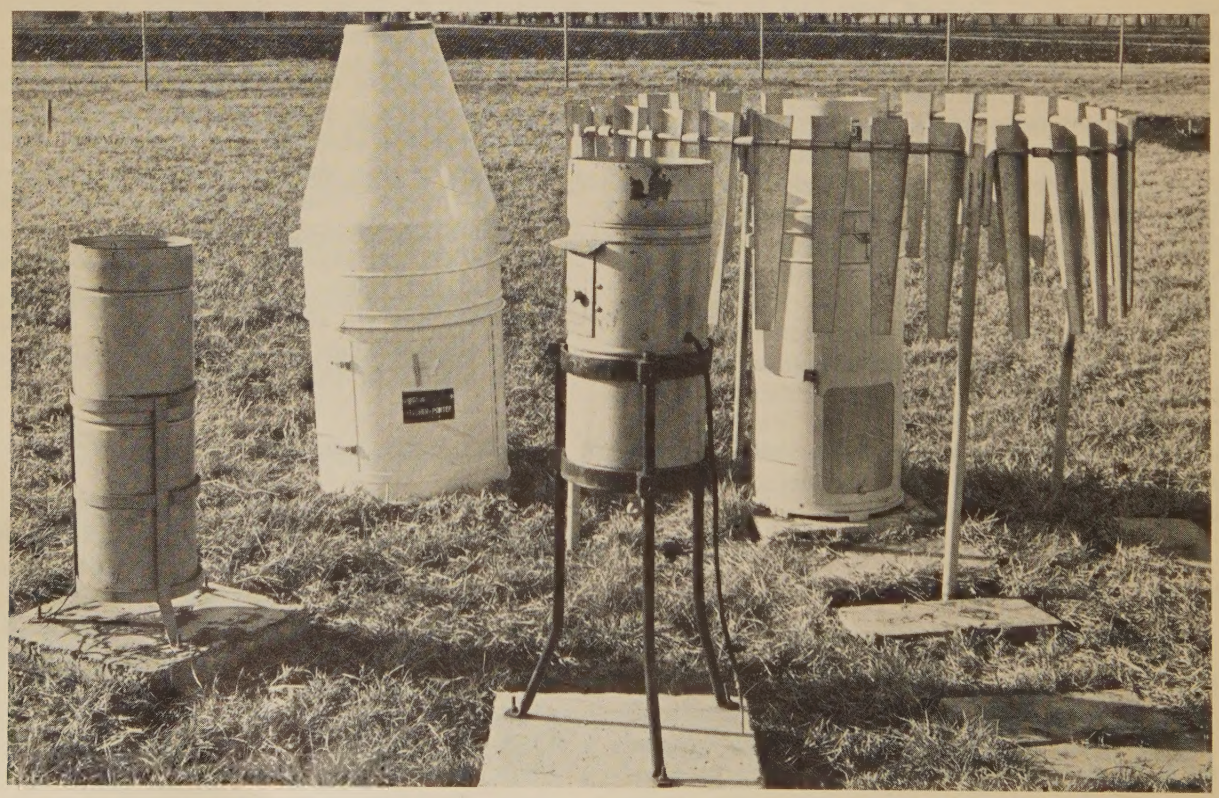


Figure 1. Standard National Weather Service Rain Gauges.

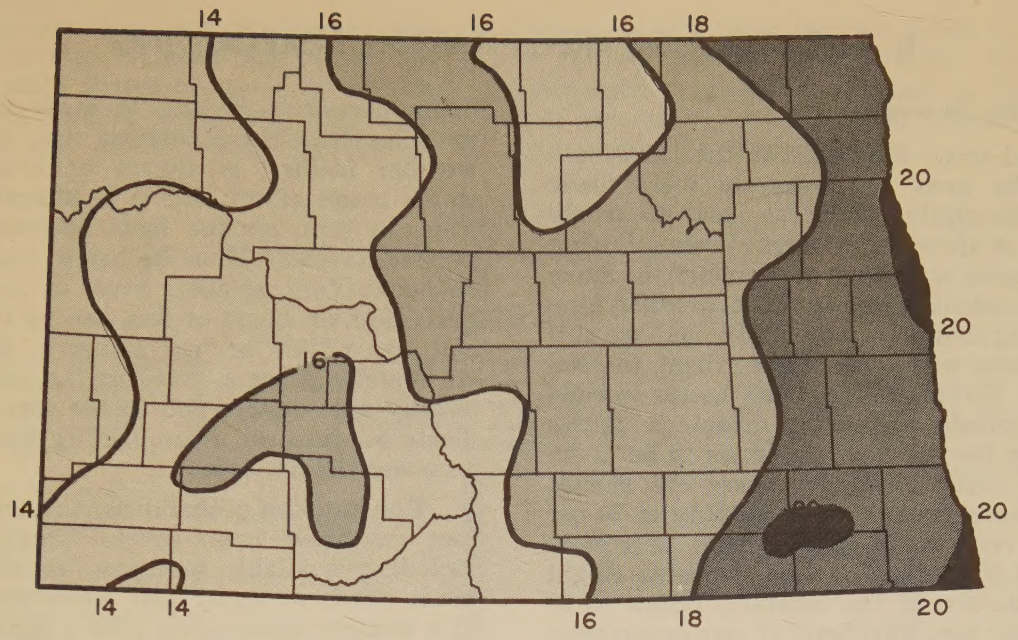


Figure 2. Mean Annual Precipitation in North Dakota (inches per year)

Measurement problems arise when nearby obstacles such as buildings and trees channel the wind flow and the path of raindrops. A rain gauge must be freely exposed, well removed from these and other obstructions.

A General Summary of Precipitation in North Dakota

On an annual basis, North Dakota receives an average of about 13 inches of precipitation in its northwesternmost area up to about 20 inches in the southeastern portions of the state along the Red River Valley (Jensen, 13; Figure 2). Jensen stated that precipitation in the state generally increases about an inch for every 50-mile increment eastward from Montana except for some irregular meanderings in the north central and southwest portions of the state which he attributed to topographic effects.

Seasonal Trends

More than 75 per cent of the annual precipitation in the state occurs during the general crop growing season. Rainfall in spring is usually light (Figure 3), increasing until late June before gradually declining through the winter.

Jensen (13) cited that during the April through September period, about 50 per cent more rainfall is received in the southeast than the amounts received in the northwestern portions of the state.

Approximately one-fourth of the annual precipitation (3 to 5 inches) in North Dakota falls as snow. Jensen (13) stated that North Dakota's snowfall is considerably less than that of any state to the east of it which borders Canada, and areas west of North Dakota receive considerably more snow. As a result, snow cover is not commonly found in the state. Maximum snow depth at any time during the winter ranges only from about 9 inches in the southwest to 15 inches in the northeast areas of the state.

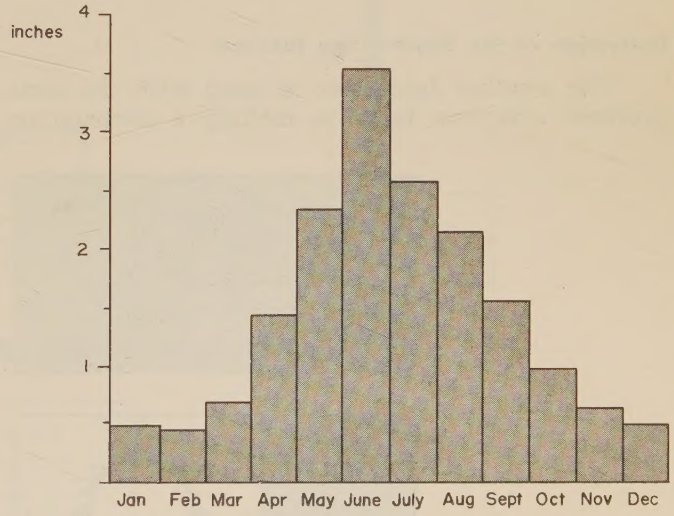


Figure 3. Mean Monthly Precipitation in North Dakota.

As stressed in the first of this series of publications on the agroclimatology of North Dakota (Ramirez, 15), climatological summaries and descriptions should not be limited simply to means and extremes of weather elements, but should include chances or probabilities of selected weather elements occurring that are critical to management-decision making in agribusiness. The likelihoods of selected rainfall amounts occurring at selected periods of the year are fully discussed in this present bulletin.

B. SHORT-RANGE PRECIPITATION FORECASTING

Per Cent Probability Forecasts

Rainfall and snow forecasts for the immediate evening and the next day formerly were made only in such descriptive terms as clear to partly cloudy, chance of showers, or general rain. Such a qualitative forecast was often not enough to make management decisions. Although such weather forecasts bear an implication of probability and are still available for those who prefer to use them, the National Weather Service (NWS) now issues worded forecasts with specific probability meanings. It is a current practice for the NWS forecasts to be given with only two word qualifiers: these are chance and likely. Chance refers to a probability of 30 per cent to 50 per cent, while likely relates to a probability level of 50 per cent to 70 per cent. Slight chance, used mainly in the summer, refers to 20 per cent to 50 per cent likelihood of rain occurrence. When no qualifying word is used and the probability of precipitation is not mentioned in a forecast, the likelihood is less than 30 per cent (20 per cent in the summer).

Cartoon illustrations in Figure 4 show the proper National Weather Service weather forecast language associated with certain ranges of precipitation probabilities.

Derivation of the Short-Range Forecast

The weather forecaster is faced with the same problem everyone faces in making a decision on many occasions—having to make decisions based upon insufficient information. Our atmosphere, the weather factory, is always an everchanging, unstable ocean of air and it is almost impossible to learn in time all the facts necessary to make a perfect forecast. Thus, he has to resort to per cent chances. Very seldom, even in immediate short periods of six hours or less, can he resolve his forecast into a "yes" or "no" category. Evidences needed to make either a "rain" or "no rain" forecast are usually not enough, and so the forecaster must indicate his forecast in probability values other than zero and 100 per cent.

Precipitation probabilities in each weather forecast are based upon several atmospheric factors, including available moisture, stability of the air mass, winds at upper and lower levels, and speed of a weather disturbance (like a thunderstorm) in a particular region. The root of all forecasts is the body of observations made at several weather stations scattered in the region. This information along with millions of bits of data from other stations is funneled to the National Weather Service's National Meteorological Center at Suitland, Maryland. In this forecast center, broad atmospheric factors that contribute to the production of precipitation are analyzed with computer assistance. This processed information is transmitted to the district forecaster for North Dakota, in Kansas City, Missouri, who adds his refinements based on his experience and more detailed knowledge of his region made up of

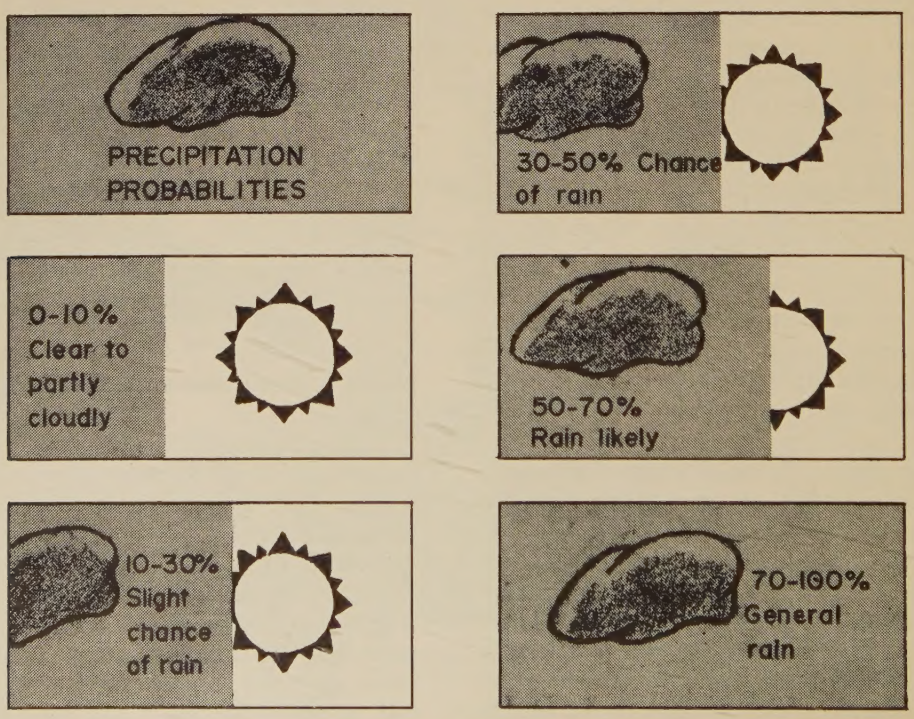


Figure 4. Precipitation Forecast Language and Associated Probabilities.

several states. The area forecaster (in Minneapolis, Minnesota) issues a state forecast for North Dakota. The within-state forecaster then further refines the forecast to smaller areas of several counties, called zones, and issues a point probability forecast within these forecast zones for the public.

A flow diagram of the weather forecasting decision-making process is outlined in Figure 5. The area covered in each of North Dakota's zone forecasts is shown in Figure 6.

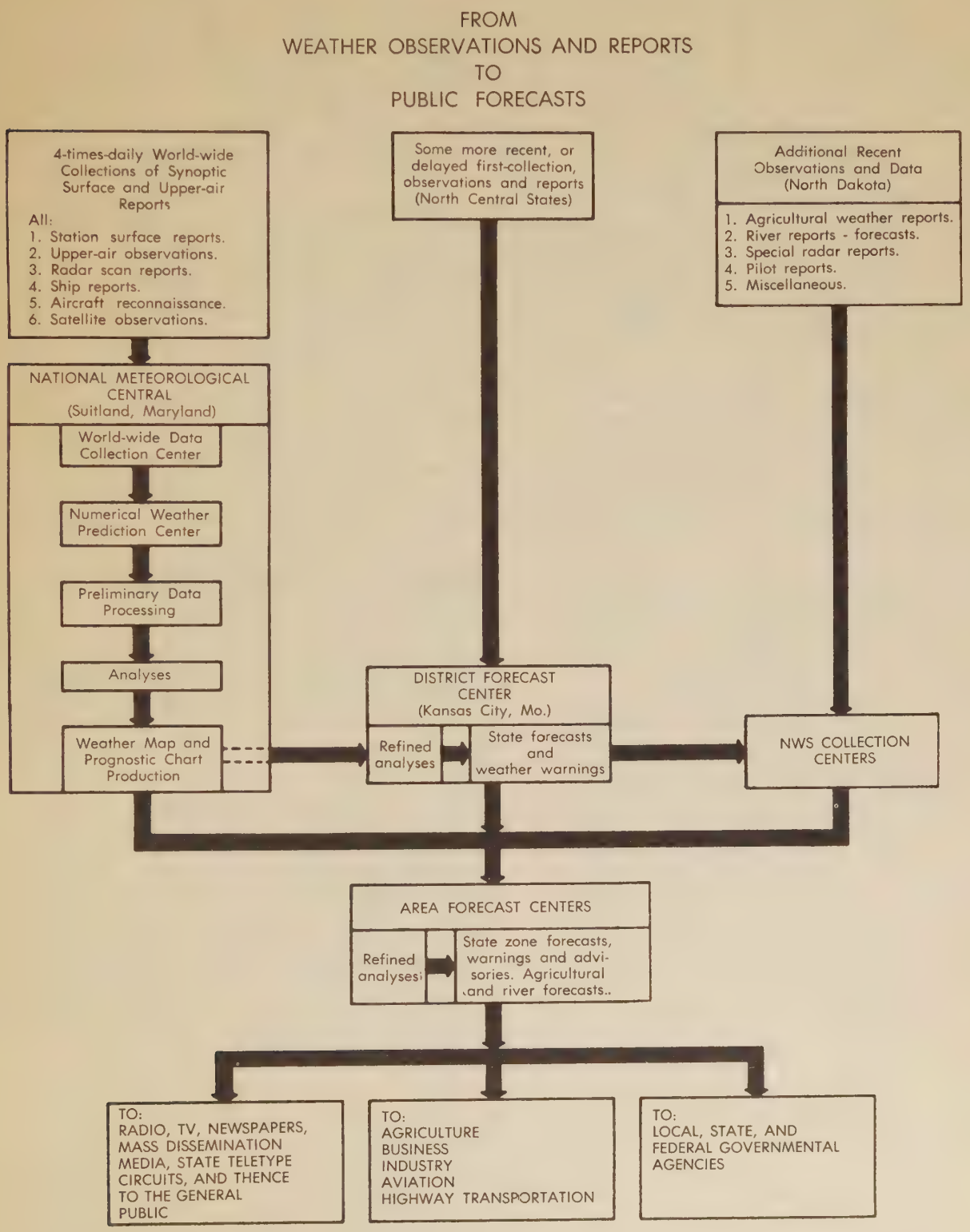


Figure 5. Schematic Diagram of the Weather Forecasting Decision-Making Process.

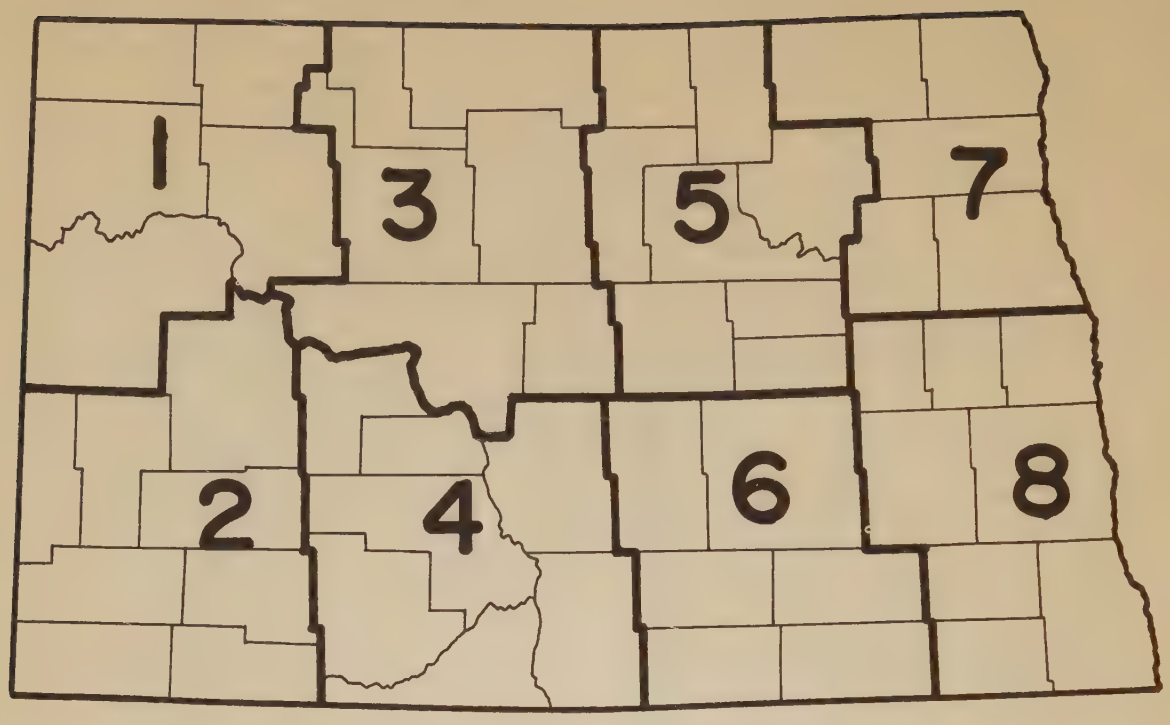


Figure 6. The Geographical Areas Covered by Zone Weather Forecasts in North Dakota.

From the information he receives, the local forecaster initially decides whether it is or it is not going to rain in his local area of concern. He estimates the per cent chance that precipitation will occur for the forecast period under consideration.

Since more evidence is usually available to the forecaster the closer it is to the time of impending precipitation, good reliability in the forecasts is expected for the most immediate forecast periods. This also means that the forecaster can more safely use near zero or near 100 per cent probability values for the forecast in the next 12 hours than he can in the forecast for the next day.

The forecaster's next decision will be on how much of his area of responsibility will receive precipitation if it does occur, since all of us have observed that it does not always rain everywhere when it rains. This is particularly true in the summer months when we have isolated shower occurrences. The forecaster may be quite certain that rain will occur but that it will be scattered. In another case, a squall line containing numerous thunderstorms may sweep across the whole forecast area. The forecaster may decide that there is an 80 per cent chance of rain at any point in the whole area, but that the rains will cover only 50 per cent of his forecast area. In such a case, the probability for rain at any one point is taken as 80 per cent x 50 per cent, giving 40 per cent probability at any one point (Bennet, et al., 5).

Interpretation of a Precipitation Forecast

What does per cent probability mean?

Given a forecast of 20 per cent chance of rain, measurable precipitation should be expected twice in 10 such forecasts; or there are two chances out of 10 that it will rain at any point in your forecast area.

What is a precipitation occurrence?

Although a sprinkle of rain may be significant to somebody painting a house or a farmer dusting or spraying, the National Weather Service considers a precipitation occurrence as a measurable amount of five-thousands of an inch (0.005) recorded to the nearest hundredth of an inch (0.01). Amounts less than this are recorded as "traces" (T), and are taken usually as zero amounts in many climatological analyses. Snow amounts are measured and recorded as melted snow.

Where is the precipitation expected to occur in an area forecast?

When rain is forecast over an area, the forecast pertains to any point in that area; your backyard, your farm, or wherever you may be in the forecast area. If you are traveling within the forecast area, then you are increasing your chance of

encountering precipitation because you are at more than one point within a period of time.

How often are precipitation forecasts made?

The National Weather Service generally issues weather forecasts for 12-hour periods, divided at 6 a.m. and 6 p.m. local standard time. This arbitrary division of forecast periods is fairly well related to man's activities but is usually not well related to the life of weather-producing systems (Bennet, et al., 5). The approximate issue times and periods covered by each forecast are as follows:

Time of Forecast	Period Covered
6 a.m.	Today, tonight and tomorrow
12 noon	This afternoon (a 6-hour period), tonight and tomorrow
6 p.m.	Tonight, tomorrow and tomorrow night
10 p.m.	Rest of tonight (a 6-hour period), tomorrow and tomorrow night.

Verification of Short-Range Precipitation Forecasts

Farmers and other forecast users must have confidence in the reliability of a weather forecast if they are to give it full consideration in management decisions. The National Weather Service continuously carries on a forecast verification program (Roberts, et. al., 16, and Hughes, 12) to appraise reliability of forecasts made, including aspects of seasonal variations and improvements over statistical forecasts.

To provide an idea of reliability scores on the forecasts made for the Fargo-Moorhead area by the National Weather Service Forecast Office located at the Hector Airport, Fargo, individual forecasts issued from March, 1970, through May, 1972, have been accumulated and compared to the actual precipitation occurrences. The results of the analyses made on these data are shown in Table 1.

The forecasts verified in Table 1 are those issued for the next 12 hours with about a two-hour lead time. For example, the forecast issued at 6:00 a.m. was made at 4:00 a.m. that morning and is for the 12-hour period 6:00 a.m. to 6:00 p.m. of that particular day. As suggested in Table 1, the 3,288 forecasts issued by the National Weather Service Forecast Center at Hector Airport for the Fargo-Moorhead Area during the two-year period indicated were correct 98.12 per cent of the time. Being in error less than twice out of each 100 forecasts is indeed remarkable.

It has been pointed out earlier that the shorter the lead time, the greater the reliability of a weather forecast. This means that a precipitation forecast issued this morning for the rest of today would be more reliable than the forecast for tonight or tomorrow. A comparison of reliability scores for forecasts made for the immediate 12 hours against those issued for the second 12-hour period is shown in Table 2.

It is conceivable that the reliability of precipitation forecasts may vary according to the time of the day and season of the year they are issued. Although no indication of amounts expected are included in precipitation forecasts, it is probable that the precipitation amounts expected may be related to the forecast percentage given. In view of these interesting possibilities, further analyses of forecast verifications are being made by the principal author with the cooperation of Mr. Vernon Hendrickson, chief meteorologist, NWS Forecast Center at Hector Airport, Fargo.

"Long-Range" Weather Forecasting

Short-range forecasts are those made for the immediate 12-hour, 24-hour, and 36-hour periods. These forecasts are based on actually observed behavior of the atmosphere at the time the forecast is given. Forecasting for longer lead times is definitely a more difficult task. The atmosphere's erratic behavior, its instability and the inherent short life cycles of many weather systems are the main

Table 1. Precipitation Forecast Verification for Fargo-Moorhead Area Forecasts Made at Hector Airport During the Period March, 1970 through May, 1972.

	FORECAST PERCENTAGE CATEGORIES USED											
Data Items	0	5	10	20	30	40	50	60	70	80	90	100
Forecast "F"	917	274	795	413	278	164	214	98	64	39	17	15
Observed 'R"	22	6	79	88	86	66	99	55	37	31	15	12
% Verified R/F	2.40	2.19	9.94	21.31	30.94	40.24	46.26	56.12	57.81	79.49	88.24	80.00
Error "E"	2.40	2.81	0.06	1.31	0.94	0.24	3.74	3.88	12.19	0.51	1.76	20.00
E X F	2,200	770	50	540	260	40	800	380	780	20	30	300

$$\text{Weighted Error} = \frac{\Sigma(EXF)}{\Sigma F} = \frac{6170}{3288} = 1.88\%$$

Table 2. Comparison of Reliability Scores of Forecasts Issued for the First 12-Hour and Second 12-Hour Periods at the Fargo-Moorhead Area (March, 1970-May, 1972).

Forecast Probabilities Issued	For First 12-Hour Period: Number of Forecasts Made	Number of Times PCPN Occurred	Percent Verified	For Second 12-Hour Period: No. of Times Forecast Made	No. of Times PCPN Occurred	Percent Verified
0	917	22	2.4	556	29	5.2
5	274	6	2.2	284	12	4.2
10	795	79	9.9	825	83	10.1
20	413	88	21.3	567	105	18.5
30	278	86	30.9	374	98	26.2
40	164	66	40.2	260	82	31.5
50	214	99	46.3	221	84	38.0
60	98	55	56.1	121	57	47.1
70	64	37	57.8	49	29	59.2
80	39	31	79.5	24	14	58.3
90	17	15	88.2	5	2	40.0
100	15	12	80.0	2	2	100.0
Weighted Error		1.88%			4.00%	

reasons that forecasts for longer than three days in advance are less reliable.

"Long-range" forecasts, however, are made and issued to the public by the National Weather Service. Mainly, they are based not only on the extrapolation of existing weather conditions, but also on the principle that sequences of weather events that occurred in the past may tend to repeat if initial conditions are the same. The basic approach is to find a period in the past when weather conditions were similar to the present, and assume that the chain of weather events that occurred then will probably happen again under the same initial conditions in the present.

The National Weather Service issues general forecasts for three to five days in advance in the form of a five-day forecast. Forecasts for six to 30 days in advance are issued twice a month in the form of Monthly Outlook Maps (Figure 7). The latter are available from the Superintendent of Documents, U. S. Government Printing Office, at an annual subscription price of $7.50.

Limitations in Weather Forecasting

A farmer whose schedule of farm operations has been spoiled by "unannounced" rain, or a house painter who has to re-do a certain job because of fickle isolated showers can easily say that weather forecasting is still far from being reliable. Despite these unfortunate coincidences, however, one cannot deny that forecasts have been accurate enough to be useful as primary guides in man's activities.

But, true enough, forecasting is still short of absolute accuracy. Although the physical laws governing the behavior of the atmosphere are well known and understood, the application of these principles requires data and analyses. Such analyses require information on atmospheric pressure, wind speed and direction, temperature, humidity and air density from many points on the earth's surface and for each of several layers in the atmosphere. These millions of bits of information are used in a mathematical model to simulate how all of these properties may interact and cause weather changes. Such complex analyses require a high-speed electronic computer. Three inherent problems exist in these procedures. First, inaccuracies can arise from sparse observational networks such as exist in the ocean areas of the world. Scientists hope that this problem may be alleviated by the use of satellite remote-sensing. Secondly, a comprehensive mathematical model of the atmosphere is an essential prerequisite, since the atmosphere cannot be brought into a laboratory for analysis. Such models, even when perfected, require a tremendous amount of data to describe the state of the atmosphere at any one instant and this presents the third problem related to computer capability. Let us say that enough data on a dense network have been gathered in time and that an accurate model has been made available. The large amount of data and necessary calculations require electronic computers that can prepare the forecasts sufficiently ahead of the time of the expected weather changes. Experts believe that for accurate numerical weather forecasts, we need larger and faster computers than those available at the present time.

Even with the solution of the above-mentioned problems, it may never be possible to predict with desirable accuracy what might occur 30 days in advance by extrapolation of the "present" stage of the atmosphere. The short "life spans" of many weather systems such as fronts and squall lines, and small-scale systems like thunderstorms limit their being accurately forecast well ahead of time. The

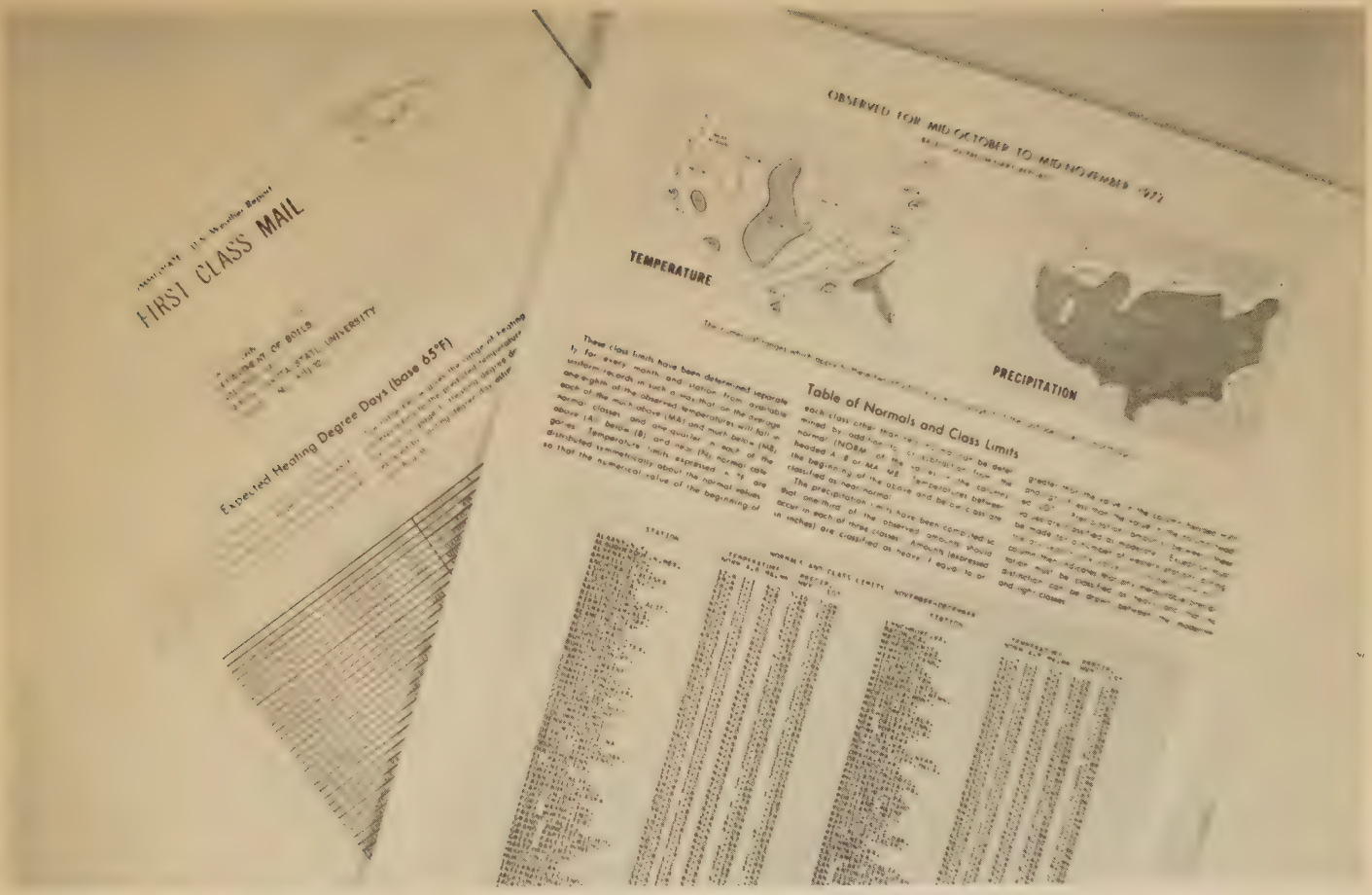


Figure 7. Monthly Weather Outlook Maps Issued by the National Weather Service.

energy cycles involved in these systems are such that as soon as one system being observed dissipates, it becomes very difficult to predict what other weather systems will follow. For this reason, many sense the futility of relying on "long-range" forecasts.

But this need not be the case. The wealth of past climatological data lends its use as a tool for climatological studies. Experience with past weather may be used as a guide to predict the probable behavior of certain weather events in selected periods of the year.

C. CLIMATOLOGICAL PRECIPITATION PROBABILITIES

Climatological Precipitation Probabilities

As pointed out earlier, the extrapolation of present-day weather becomes less reliable as the forecast lead time increases. Weather forecasting accuracy is such that it is virtually impossible to foresee from the present atmospheric conditions what the weather will be during the coming growing season. Well-kept records of past weather go back many years. If climate, which might be defined as average weather over a long period of time, does not change greatly, then we would expect the weather in the next 30 years for instance, to be about the same as it has been in the past 30 to 50 years. Using that assumption, climatologists use tremendous volumes of past weather data to gain insight into future weather conditions from historical experience.

Such climatological forecasts will not answer satisfactorily the question of, "Will it rain tomorrow?" This appraisal can only be made by analyzing weather charts showing the current weather. But the meteorologist's charts give little indication of what the weather will be a month later. To get an insight into the long-range weather picture, it is necessary to evaluate past climatic data. Using modern tools of statistics and high-speed computers, large volumes of climatic data may be examined to calculate chances of a certain weather event occurring at any specific time of the year. Knowledge of climatic probabilities, together with knowing your

own operating resources, can help you assess your chances of failure or success due to weather. Knowing the odds that a particular weather event will occur can be well worth consideration in the decision-making processes of running an agribusiness.

Statistical Procedures Used for Describing Precipitation Probabilities

In evaluating drought hazards in Iowa, Barger and Thom (1) fitted the incomplete gamma function distribution, and further cited in their paper that this statistical distribution can be used to estimate weekly rainfall probabilities. The method fits a Pearson Type III curve to the distribution of weekly, bi-weekly and tri-weekly precipitation totals, and is further discussed by Thom (17, 18) and Friedman and James (10). Barger, Shaw and Dale (2) used this method to describe the chances of receiving given precipitation amounts during specified time periods at selected North Central stations. They cited in their study that as a rough approximation, the probabilities calculated by this procedure are correct within five to 20 per cent, with an expectancy of 95 per cent. In other words, if a probability of 60 per cent chance for a given amount of rain is given, you can be 95 per cent sure that it actually lies between 55 and 65 per cent.

This present publication used the incomplete gamma function as suggested by the above authors in calculating the likelihood of receiving specified amounts of rain at selected weeks of the year. The procedure was applied on long-term records of daily climatic data from 35 selected stations in North Dakota (Figure 8).

GROWING SEASON RAINFALL

It is evident in Figure 3 that North Dakota receives most of its annual precipitation during the growing season. The time of rainfall occurrence is as important in plant growth as the amount that falls. It is frequently observed that rain comes when you least need it, and does not come when you most want it. For this reason, agribusiness is always a gamble. One might, however, refer to the average behavior of weekly precipitation in his place of business and accordingly use it as a guide to pre-plan his farm operations. Figure 9 shows the weekly rainfall totals on the average across North Dakota from March 1 through October 31.

Weekly precipitation in the state gradually increases from about one-tenth of an inch (0.1) in early March to about a half-inch (0.5) per week in late April, with amounts generally increasing southeasterly. In May and early June, weekly rainfall amounts range from about a half-inch to almost one inch a week, and amounts generally decrease as one goes almost directly north. Weekly rainfall in mid- to late-June becomes more or less evenly distributed across the state, with amounts ranging from 0.75 inch in the northern to one inch in the extreme southeastern portion of the state.

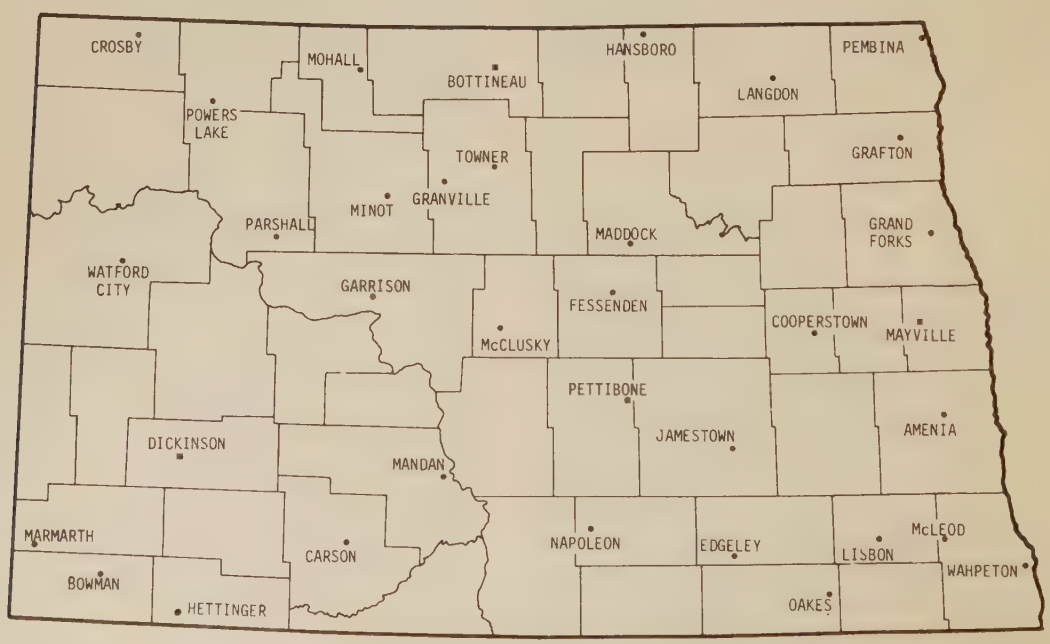
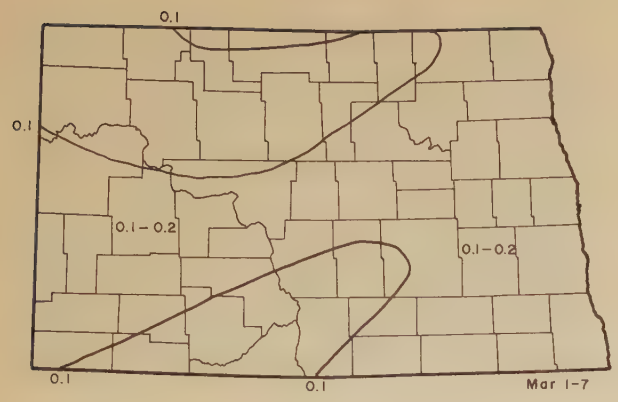
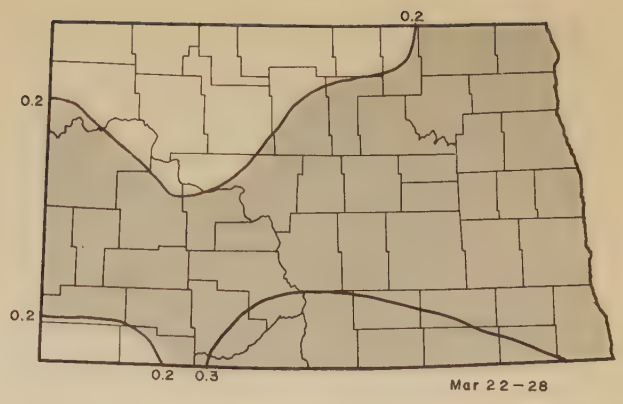
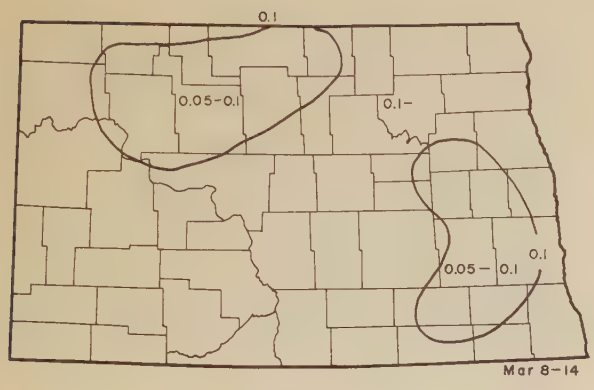
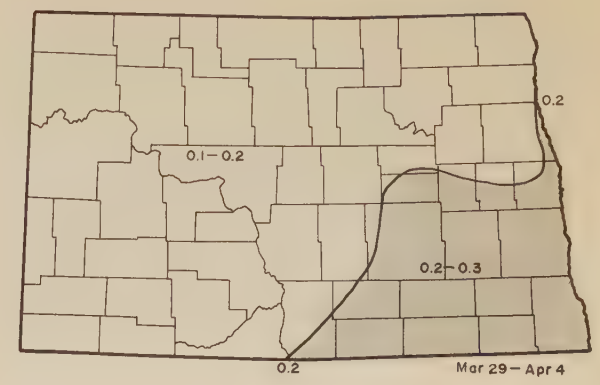


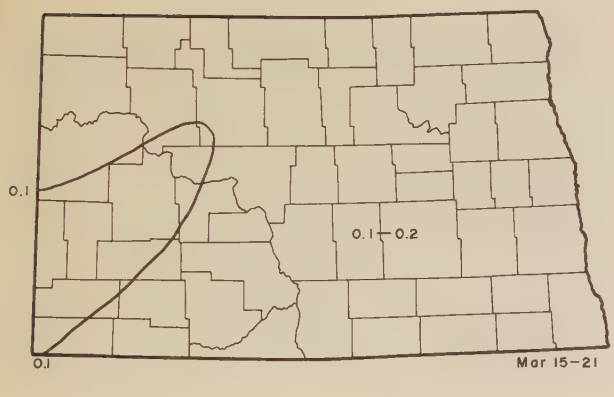
Figure 8. The Location of the Climatological Stations Used in the Precipitation Probability Analyses.

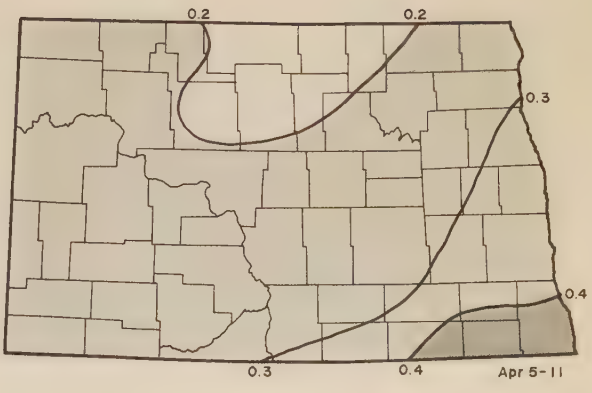












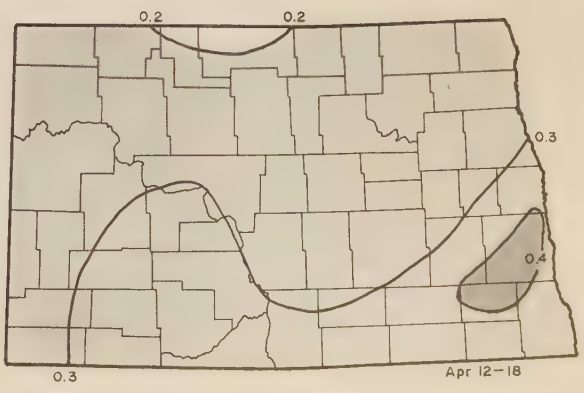
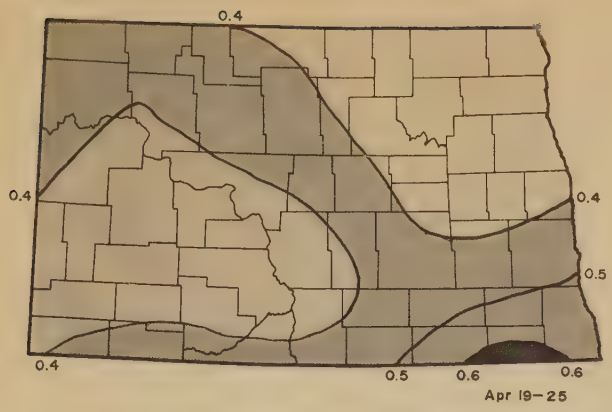
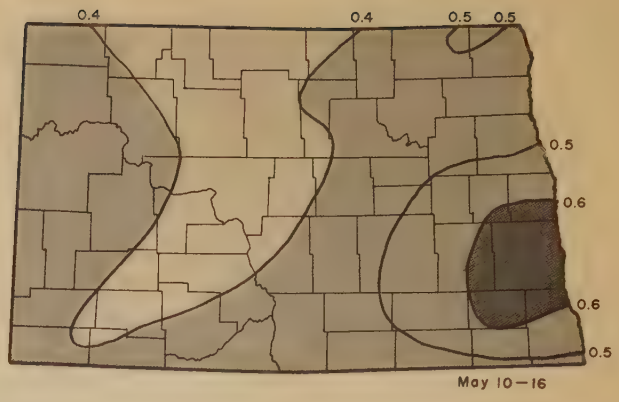
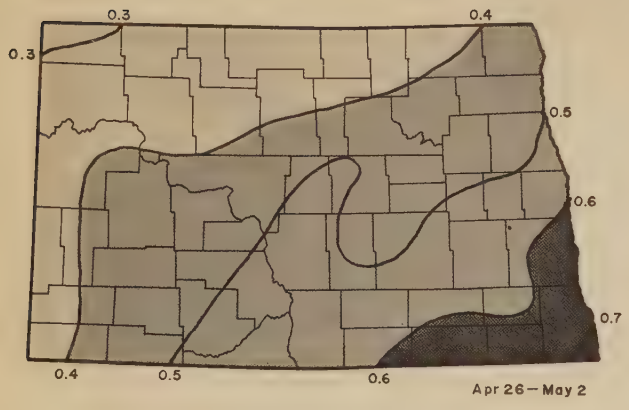
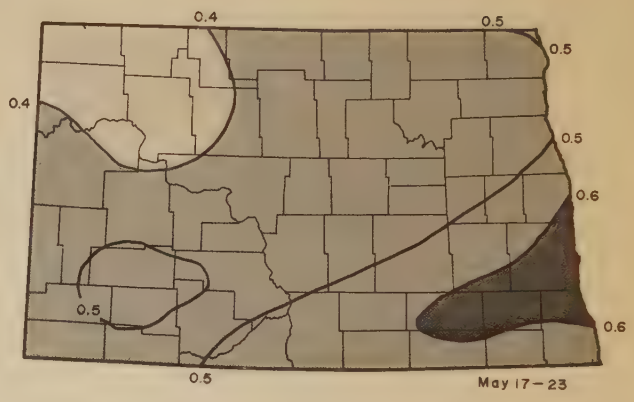


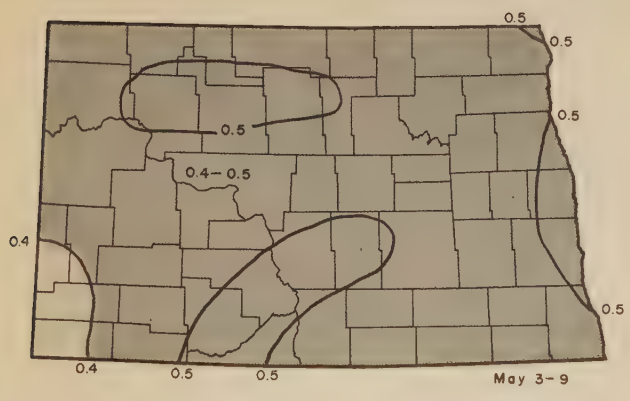
Figure 9. Weekly Average Rainfall Across North Dakota.

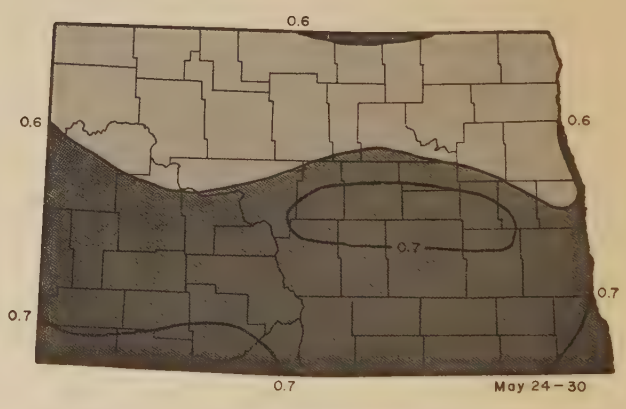


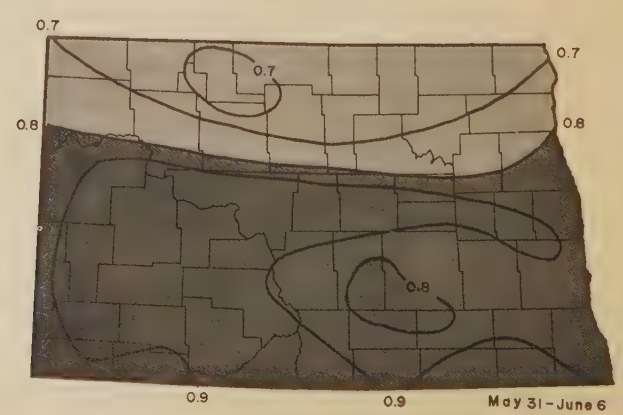












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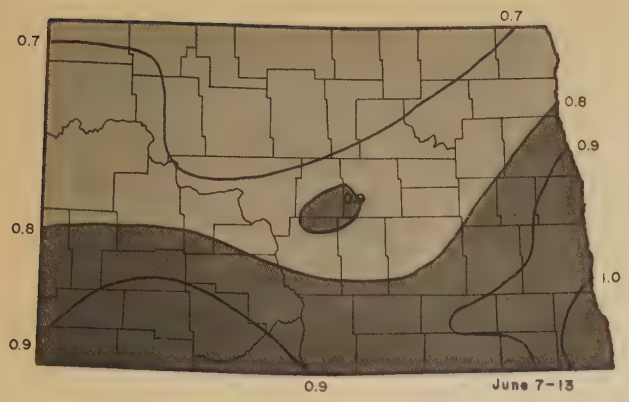

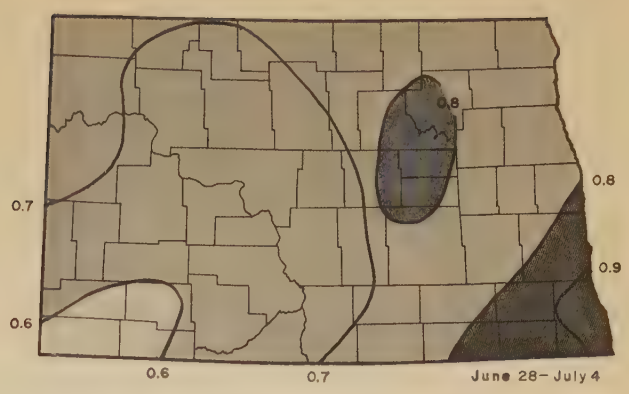

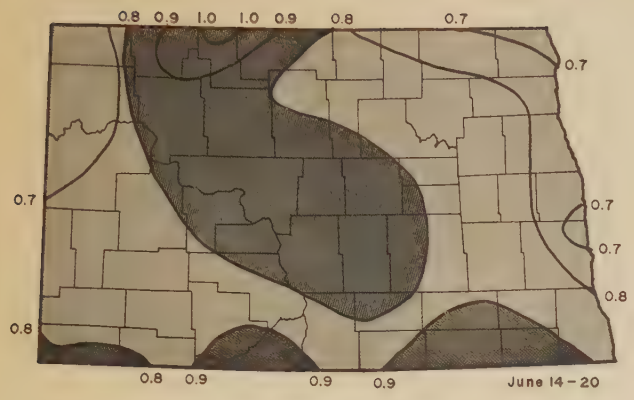

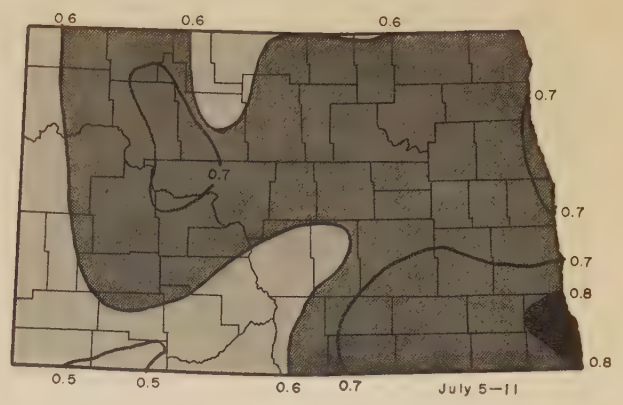

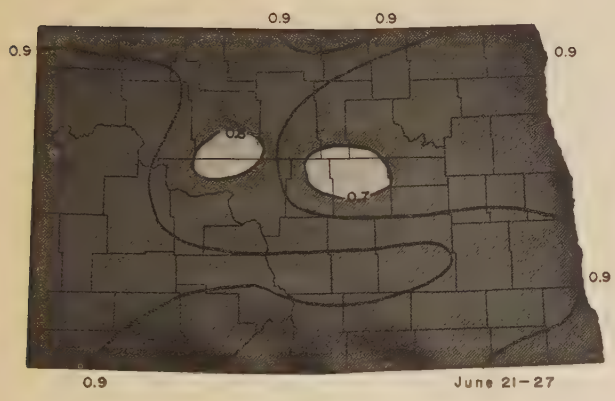

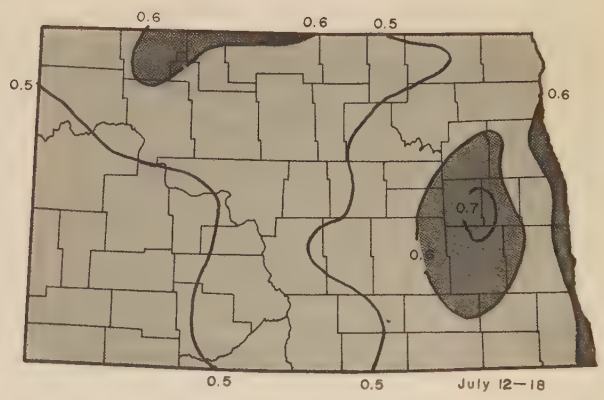

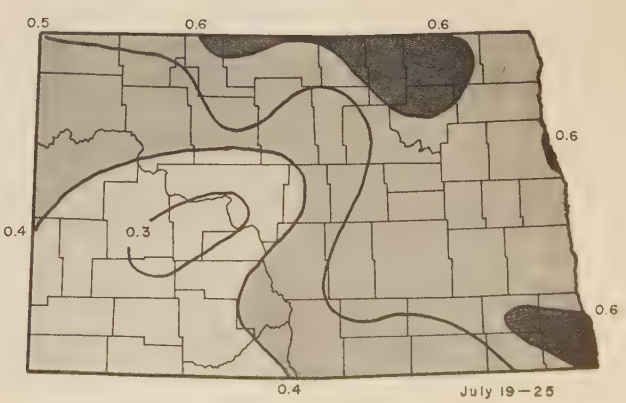

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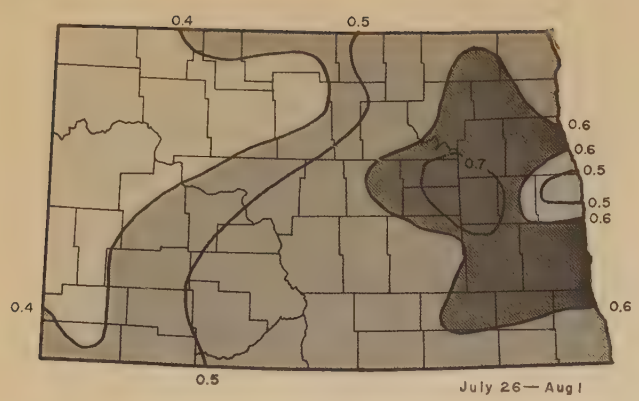

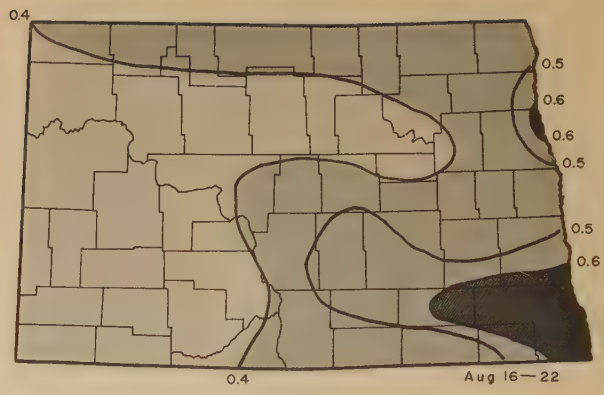

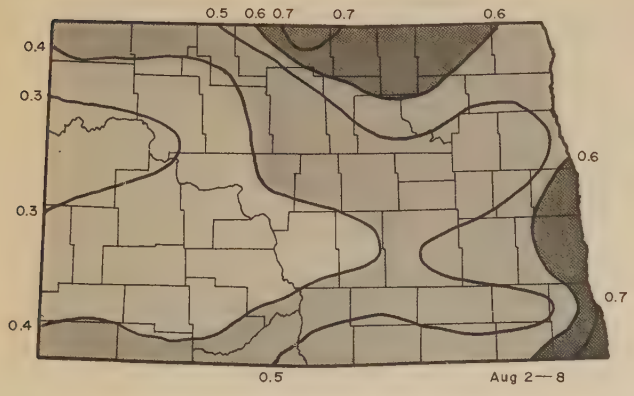

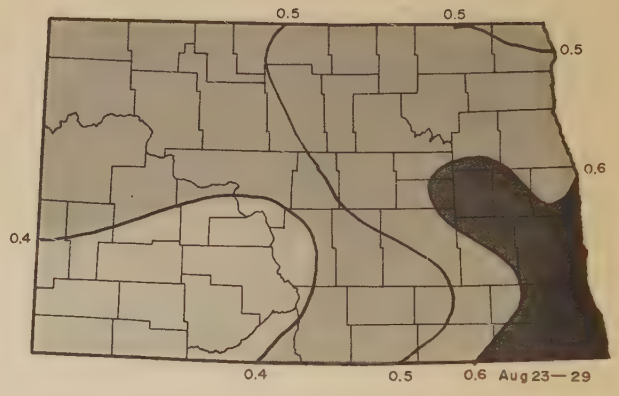

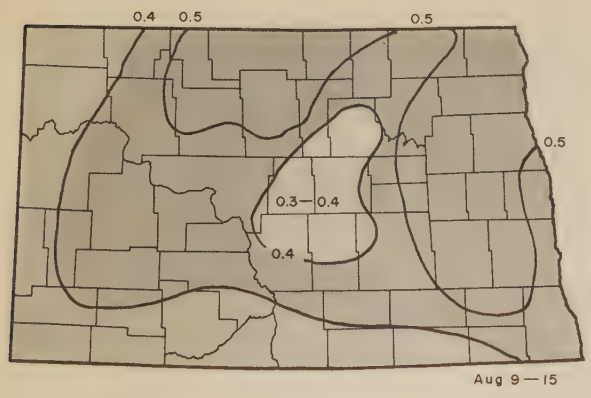

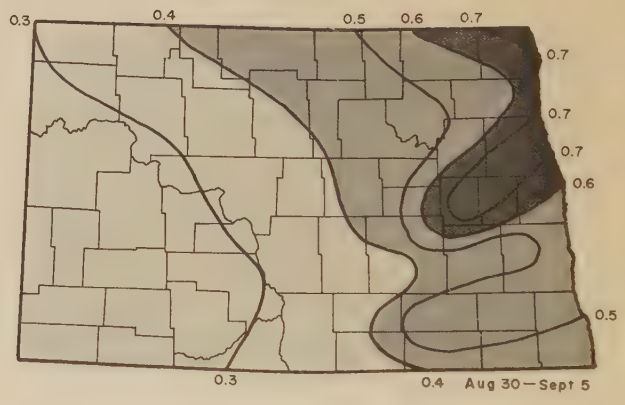

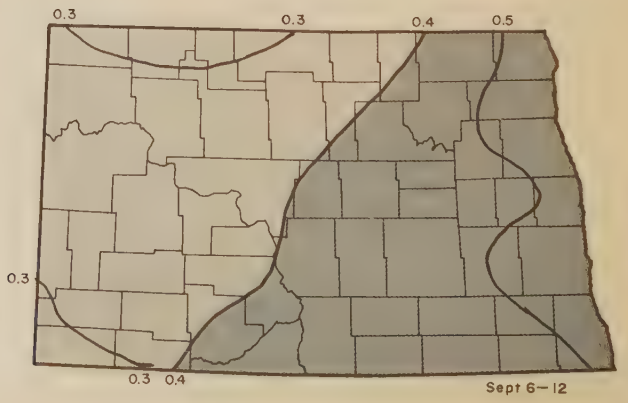

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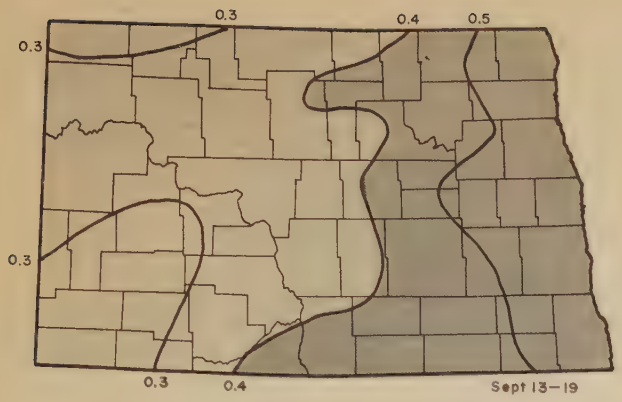

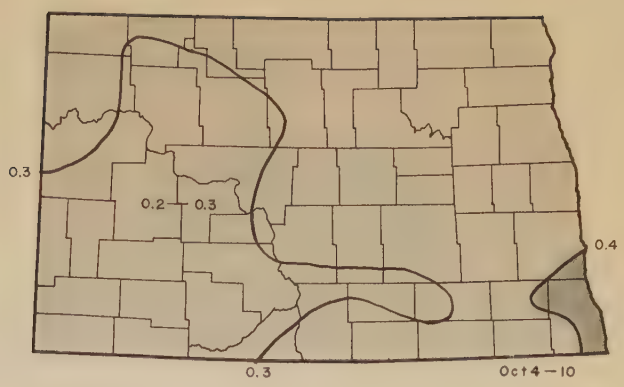

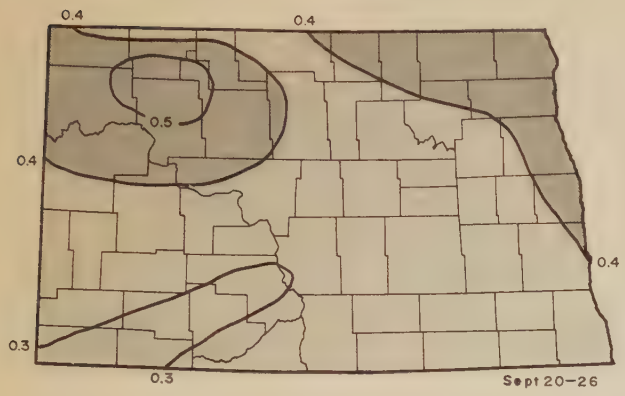

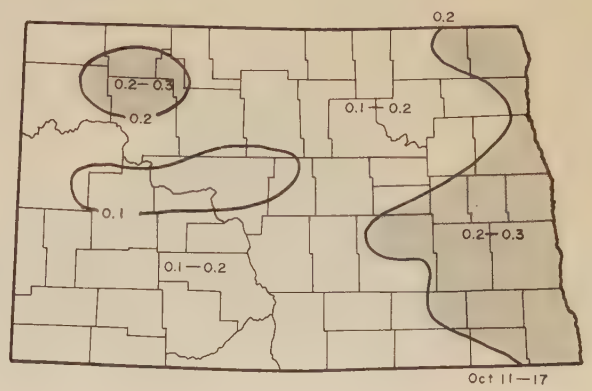

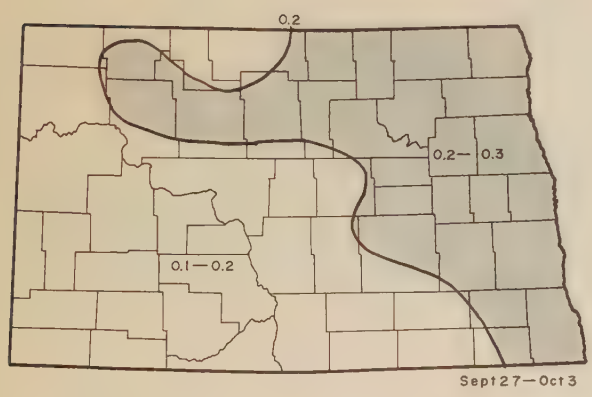

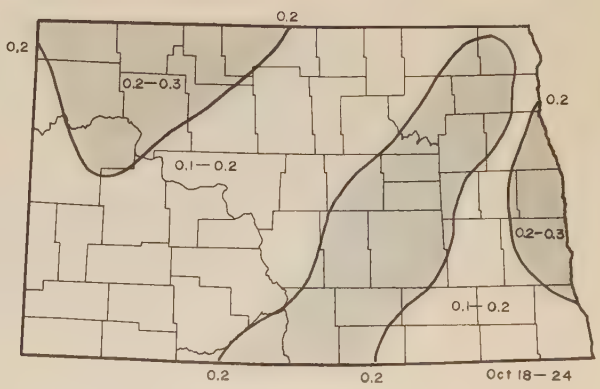

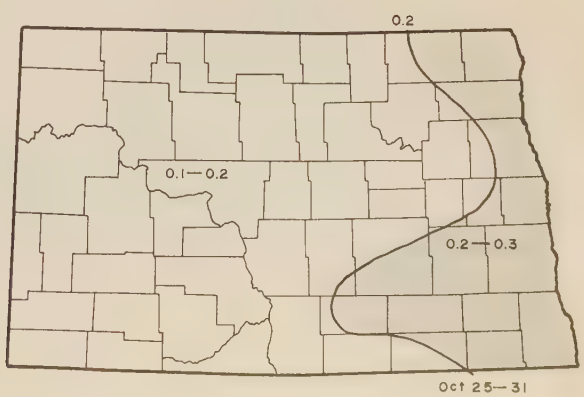

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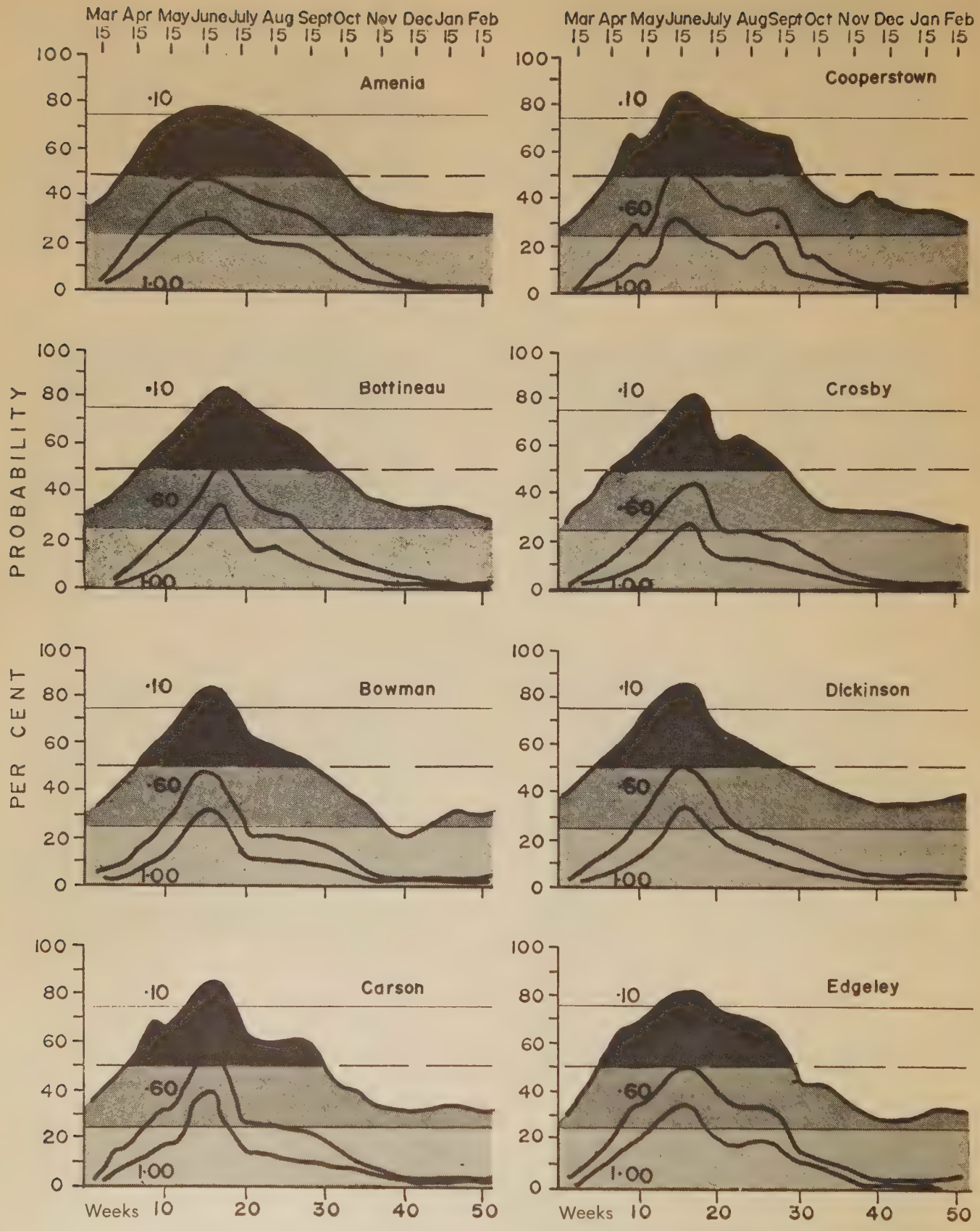
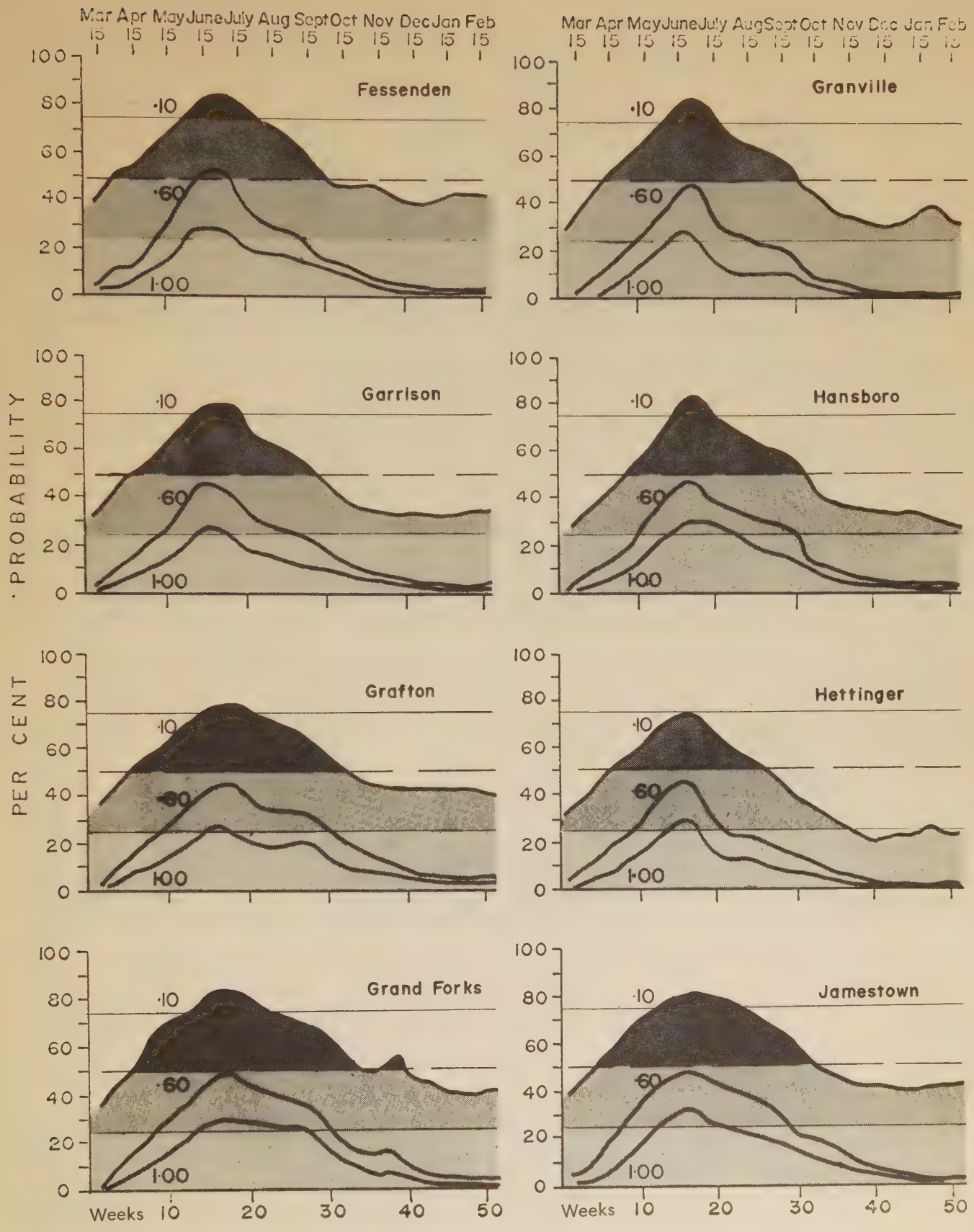


Figure 10. Probabilities of Receiving Selected Amounts of Weekly Precipitation at 35 Selected North Dakota Stations.



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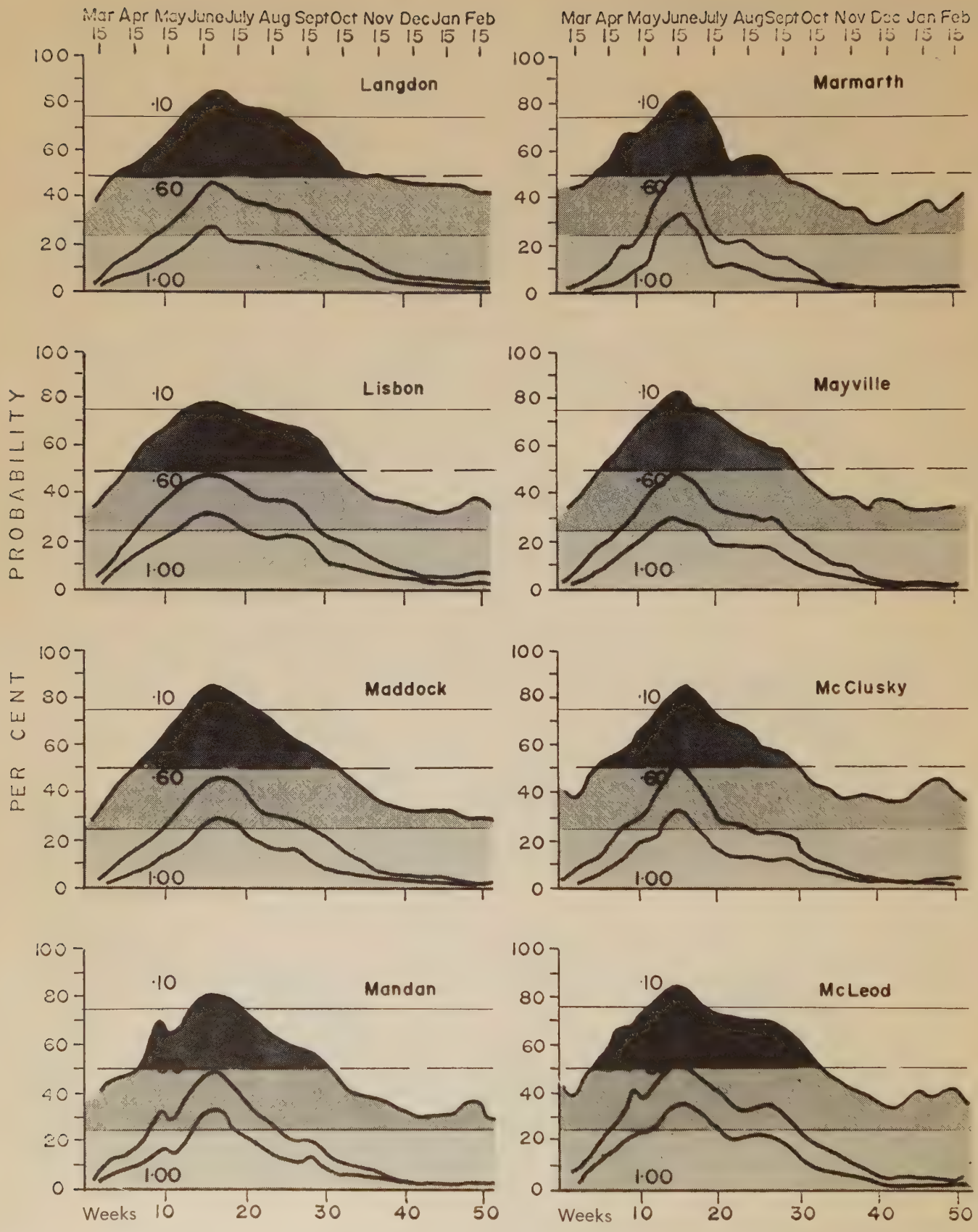

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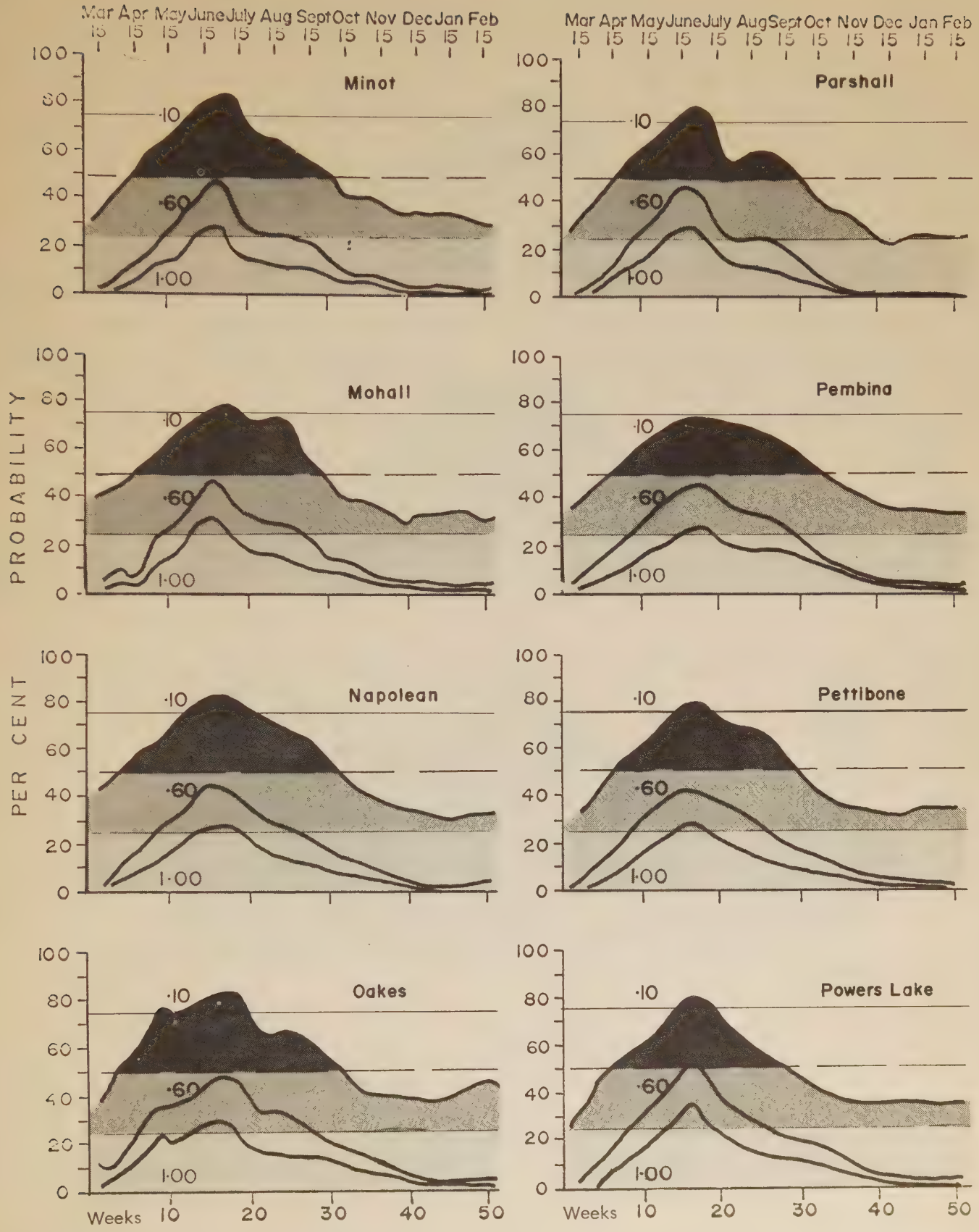

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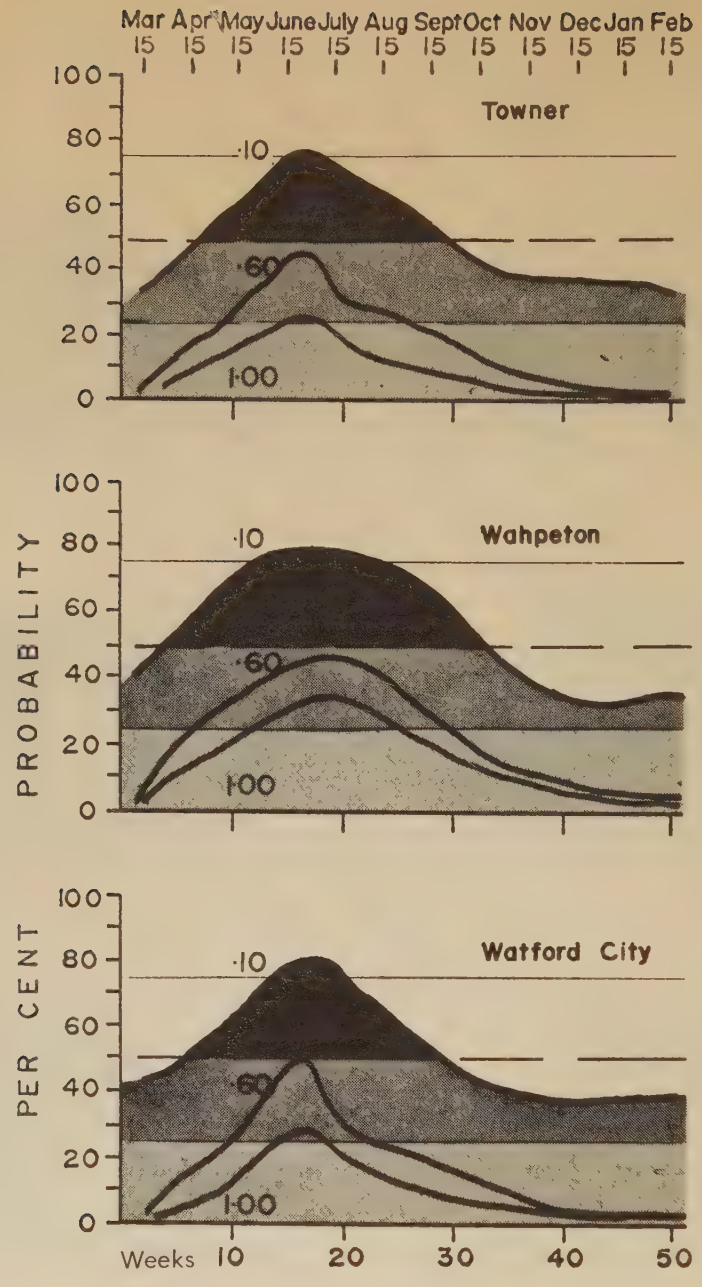


Figure 10. (Continued)

In July, weekly precipitation trends shift geographically from around 0.4 inch in the southwest and generally increase northeasterly up to about 0.7 inch per week. Similar trends exist in August and become more distinct in September when weekly amounts average from about one-third inch in the southwestern portions up to about one-half inch per week along the Red River Valley. In October, the weekly rainfall amounts range from less than 0.2 of an inch to about one-quarter of an inch per week across the state, increasing in the general west-to-east direction.

The probabilities of receiving three selected amounts of precipitation (1.0, 0.5 and 0.10 inch) for each week of the year at 35 stations in North Dakota are presented in Figure 10. In these graphs, precipitation during the winter months is indicated as melted water. It is evident from Figure 10 that the chances of receiving more than one inch during any given week of the year are very slight (0-30%) at all locations in the state. The best chance of getting an inch per week exists in mid-June, and even then the likelihood is only about one out of every three years. During the growing season, the probabilities of receiving 0.6-inch per week in all locations range from 30 to 50 per cent. Further discussions on significance and practical use of the graphs presented in Figure 10 are cited in the following sections.

Chances of Receiving Critical Rainfall Amounts During the Growing Season.

Rainfall Probabilities in the Spring

In a comprehensive review of literature and from field studies, Bauer (4) summarized the effect of water stress at various growth stages on grain yield reduction in wheat (Figure 11). His results showed that up to 20 per cent reduction in wheat yield may be caused by water stress inflicted during the emergence, tillering and boot stages of the wheat plant growth and development. Similar observations have been pointed out by the same author for grain corn and soybeans. It is evident from these studies that soil moisture in the spring is highly significant to crop success or failure.

Most of the soil moisture needed for plant emergence and early development in the spring is supplied by moisture stored during the previous fall and winter. This supply can be depleted readily if not augmented by timely rainfall. In the cooler spring months, evaporation loss rate is small, but becomes progressively greater as summer approaches.

Figure 10 shows that the chances of receiving more than 0.6-inch of rain per week in the months of March, April and May in North Dakota are slim, ranging only from less than 10 per cent to about 40 per cent. This amount per week compares closely

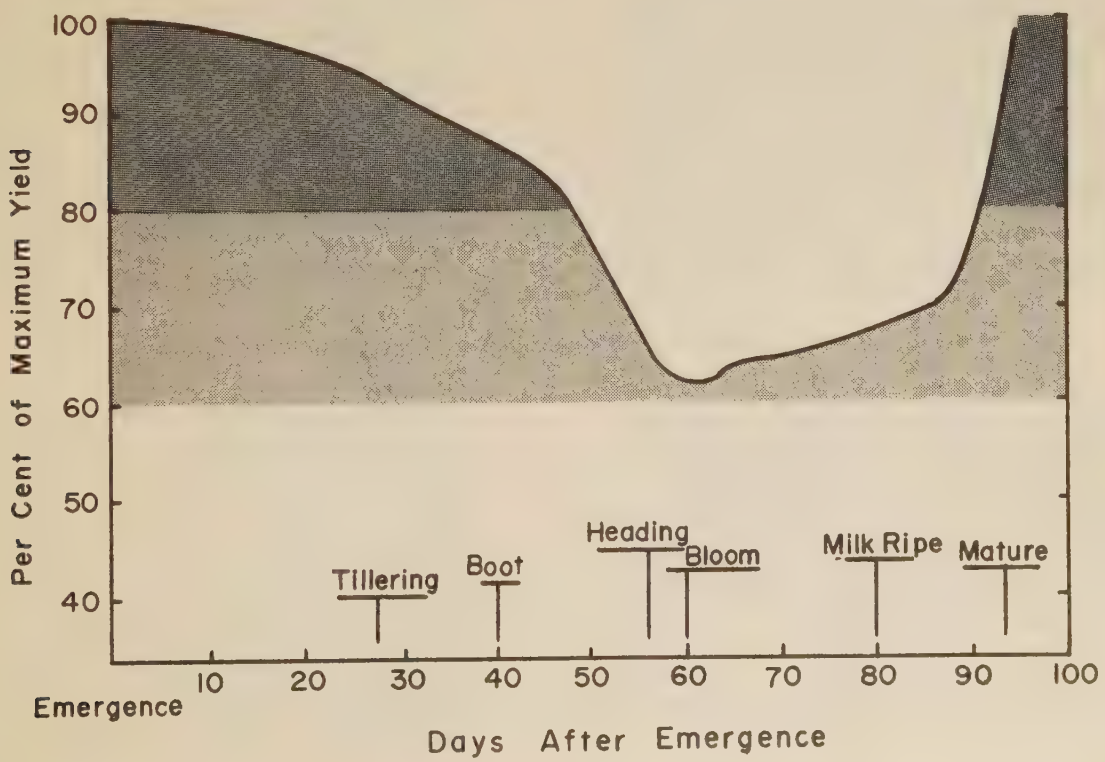


Figure 11. Effect of Water Stress at Various Growth Stages on Grain Yield Reduction in Wheat.

to the average amount of evaporation and transpiration in the cool months of the spring. The probabilities of receiving lesser amounts per week are obviously higher, but these follow the same trend; that is, probabilities increase as the growing season progresses. This upward trend of increasing probabilities continues until about the middle of June when it peaks, then starts decreasing again as the year advances.

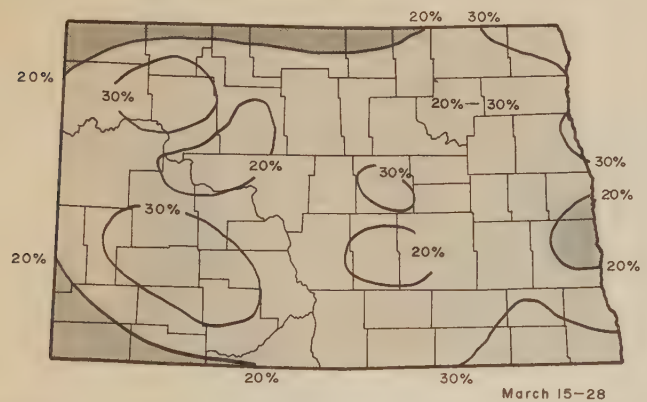
The maps of Figure 12 are presented to give a better insight into the geographical distribution of the probabilities of receiving stated amounts of rain in selected two-week periods during the growing season. The chances for receiving at least 0.6 inch of rain in the middle two weeks in March and April (Figure 12a); at least 1.6 inches in mid-May (Figure 12b); and 2.0 inches in mid-June (Figure 12c) are shown in these figures. These amounts, although arbitrarily chosen, might be considered critical since they approximate the potential loss of water from soils and crops by demands of the atmosphere during the specified periods.

In March, the chances for receiving at least 0.6-inch in two weeks are less than 30 per cent across the state. Better chances exist in mid-April with probabilities up to 60 per cent in Ransom county, but as low as 30 per cent in the northwesternmost portions of the state.

In mid-May, the likelihood of receiving at least 1.6 inches in two weeks is generally less than 20 per cent, with slightly higher chances in the southeast. In mid-June, there is about a 30 to 40 per cent chance of getting two inches in two weeks in the southern half of the state, and 20-30 per cent probabilities in the other half.

Chances of Rain During the Hot Summer Months

It was pointed out earlier in this series (Ramirez, 15) that the damaging effects of extended periods of high temperatures are aggravated when associated with prolonged lack of precipitation. It is during these hot summer months when maximum potential water loss through evaporation and transpiration occurs. In almost all locations in the state, the highest temperatures occur in late July and early August. During these periods, the atmosphere's demand for water can be as much as one-third of an inch per day in North Dakota. As a basis for describing rainfall probabilities during this period, the likelihood of receiving at least one inch of rain per week across the state from July 12 through August 15 is presented in Figure 13. One inch per week of rainfall might be considered significant, since a rate of 0.25 inch of water loss per day by evaporation and transpiration during these periods



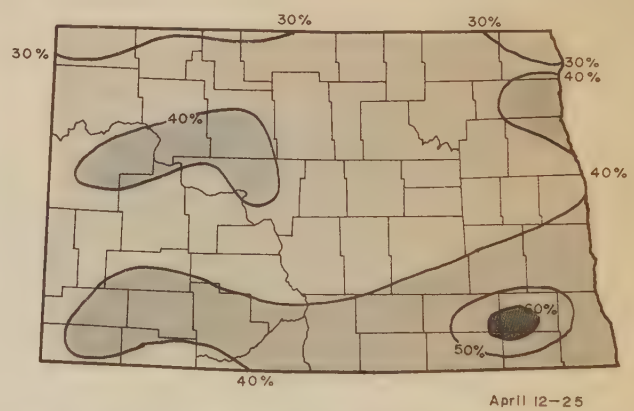


Figure 12a. Chances of Receiving at Least 0.6 Inches of Rain in the Mid-Two Weeks in March and April.

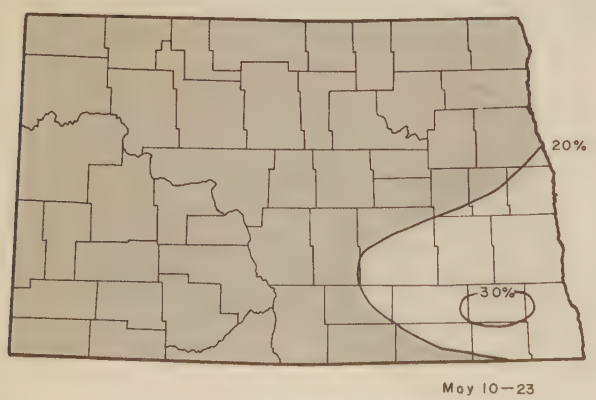


Figure 12b. Chances of Receiving at Least 1.6 Inches of Rain in the Mid-Two Weeks in May.

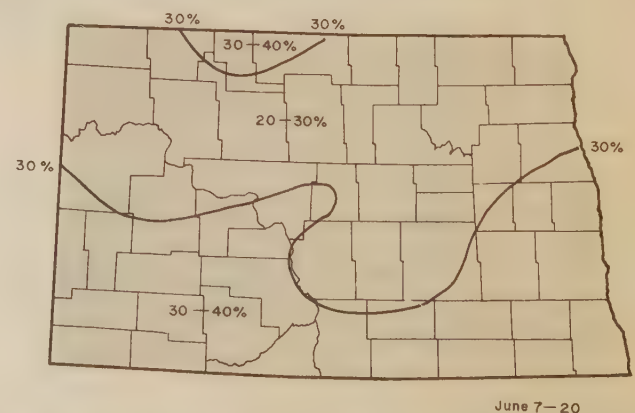


Figure 12c. Chances of Receiving at Least 2.0 Inches of Rain in the Mid-Two Weeks in June.

suggests that 1.75 inches of water is lost each week. Lack of rainfall to compensate at least for part of this loss will be damaging to crop yield, as shown in Figure 11.

In the warmest weeks of the year, the chances of receiving at least an inch of rain per week are slim, ranging from less than 10 to about 30 per cent across the state. The chances are a little better in the southeast and the Red River Valley.

Rainfall at Harvest Time

Rainfall occurring at an improper time during grain harvest in the state can be damaging to final yield and quality of the crop. Jensen and Lund (13) pointed out that wetting from exposure to rain and even dew could lower the test weight of the grain. Rainfall on swathed grain is indeed undesirable.

The chances that no measurable amounts of rain will occur in some particular week during the growing season are shown in Figure 14. According to this graph, the chances that there will be week-long periods of no rain in mid-July through the end of October, corresponding to the general harvest time in North Dakota, hardly exceed 50 per cent. The probabilities of no rain generally increases during late summer from about 20 per cent to 50 per cent across the state. Further discussions on these graphs are included in the following section.

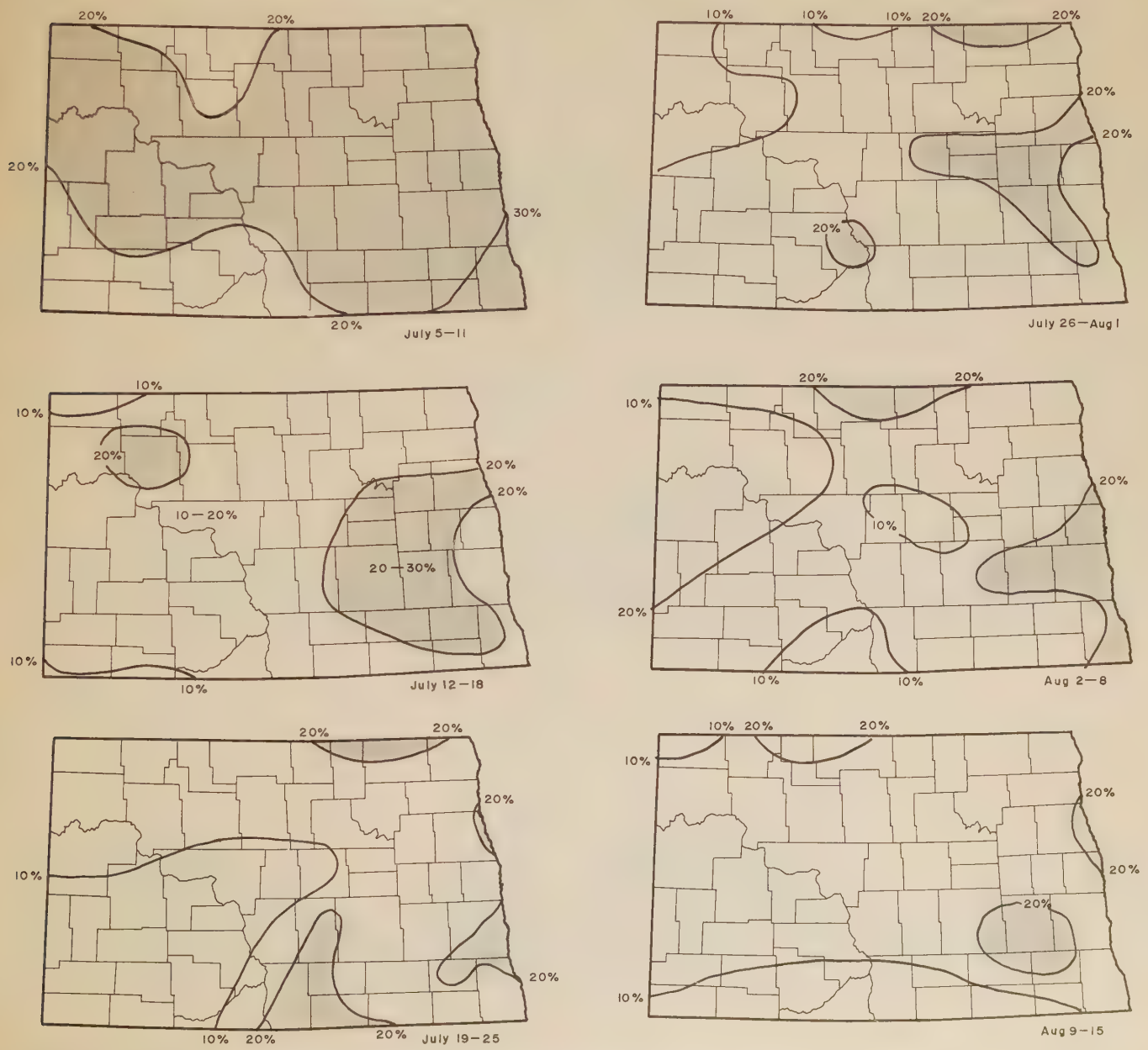


Figure 13. Likelihoods of Receiving at Least an Inch-per-week of Rain in July and August.

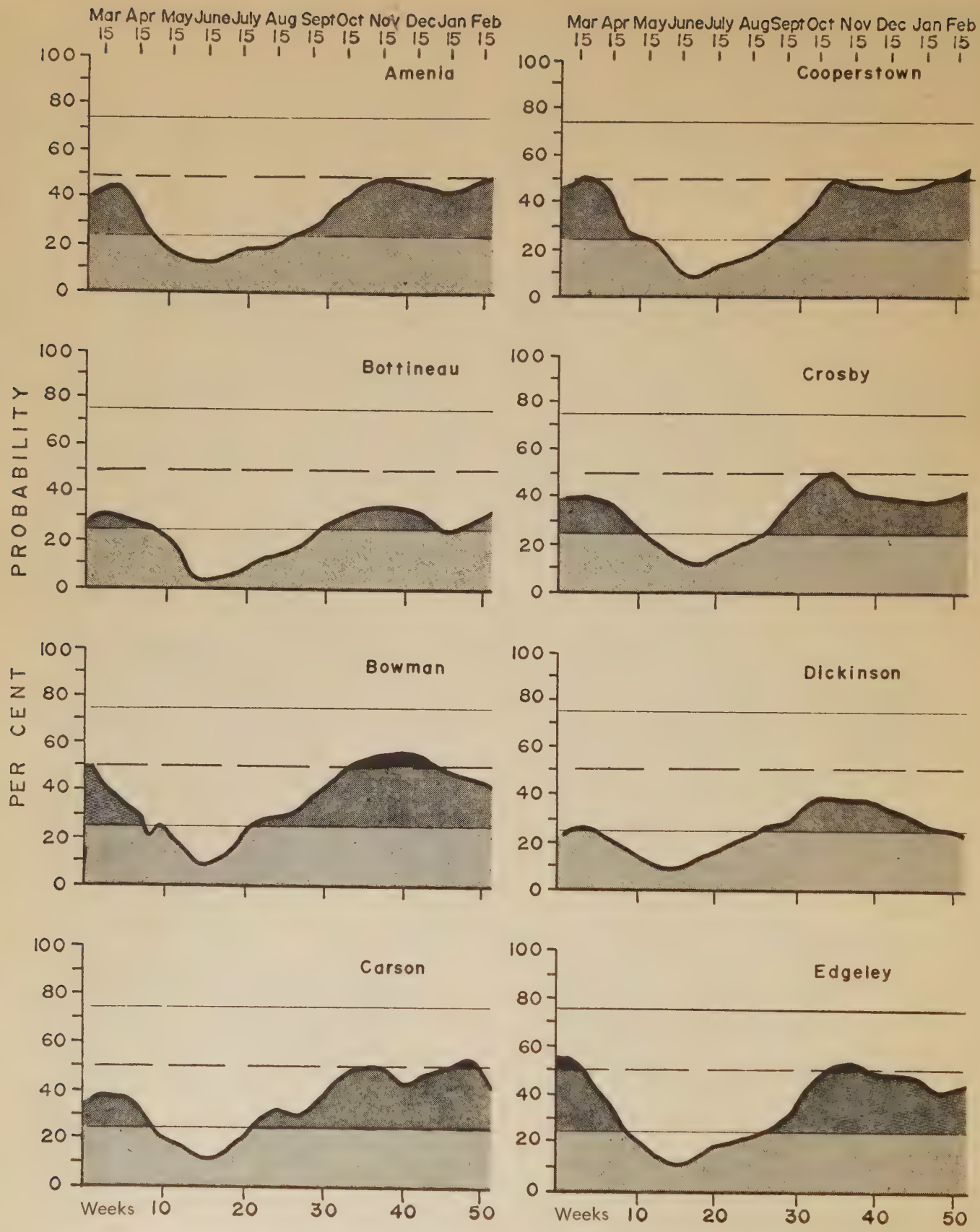


Figure 14. Probabilities of Receiving No Measurable Amounts of Precipitation in any Week of the Year.

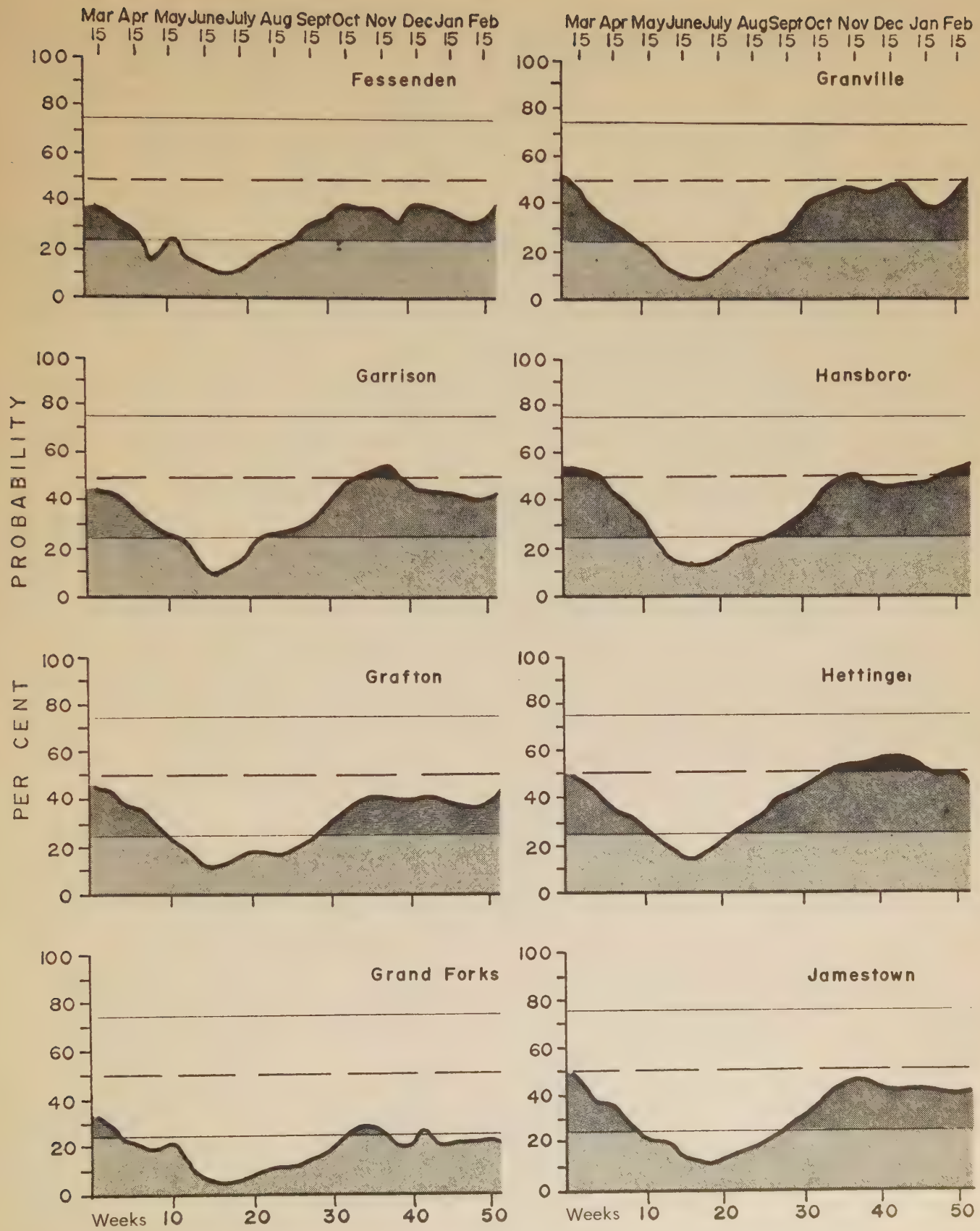


Figure 14. (Continued)

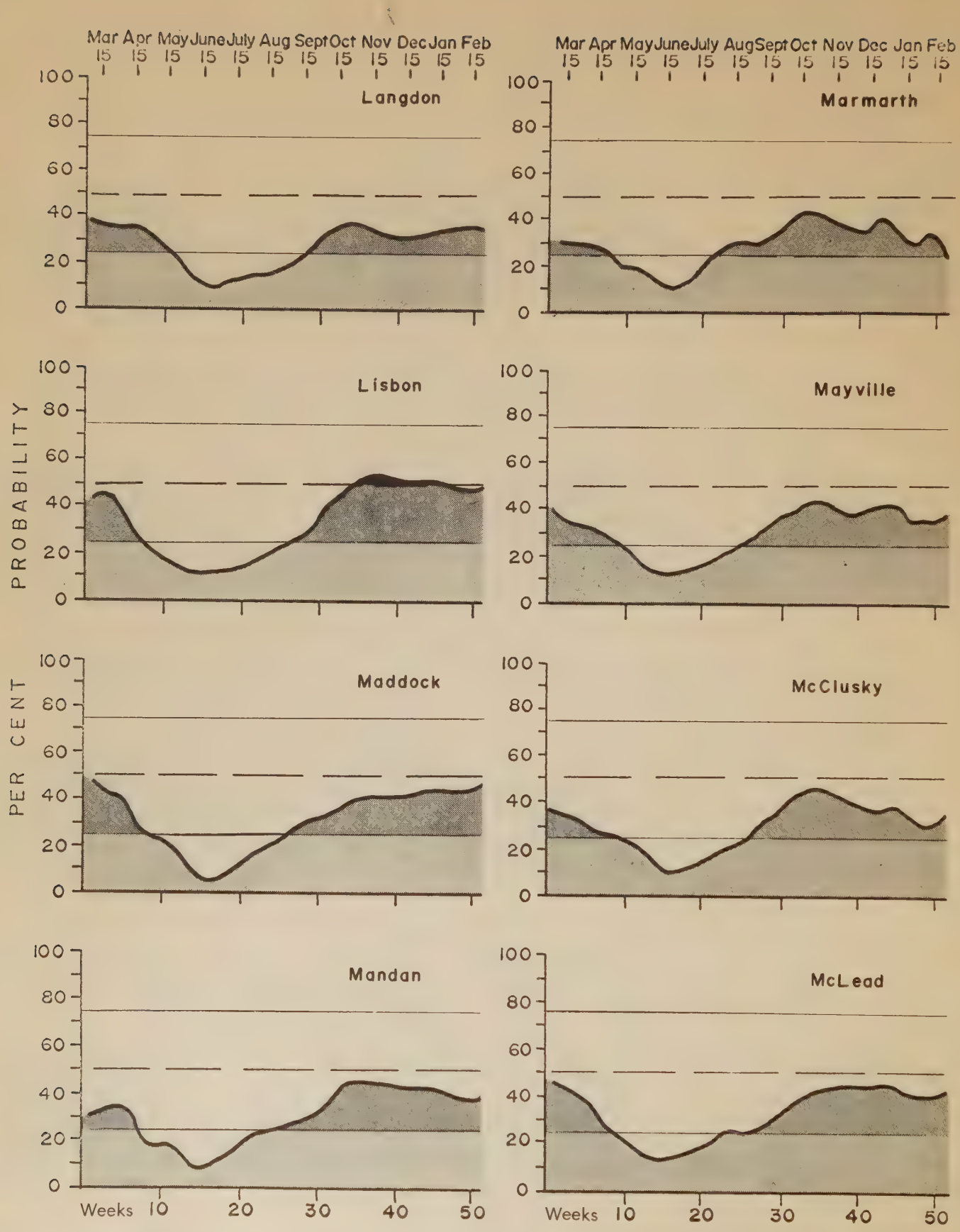


Figure 14. (Continued)

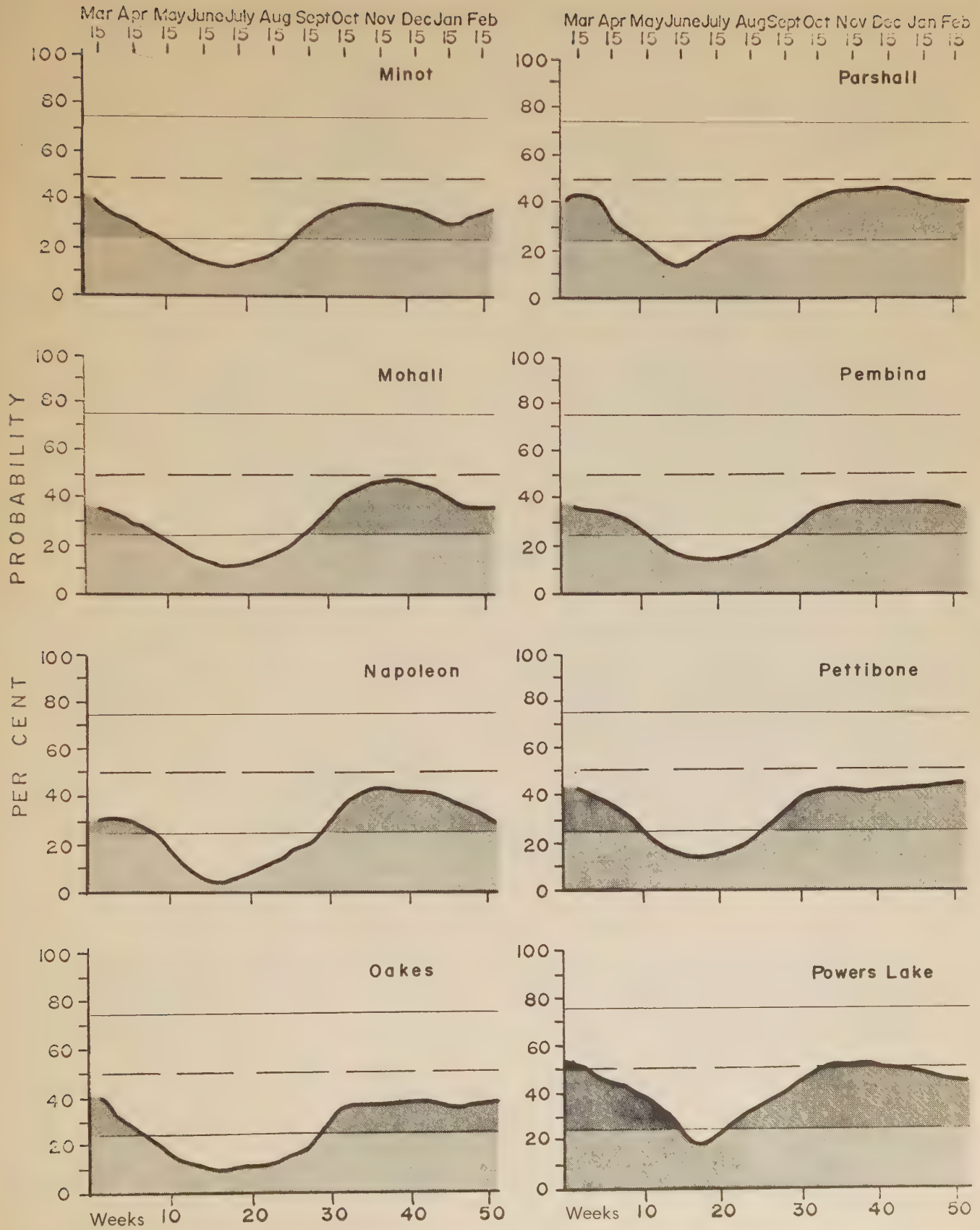


Figure 14. (Continued)

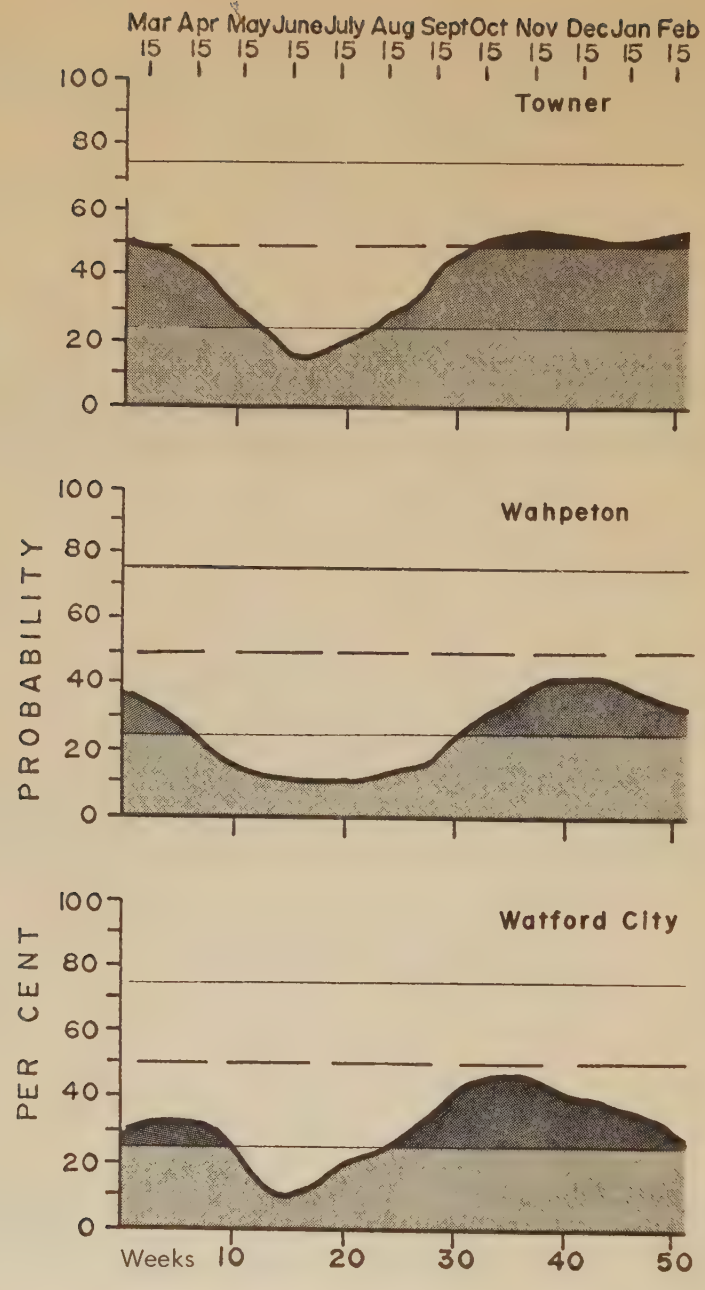


Figure 14. (Continued)

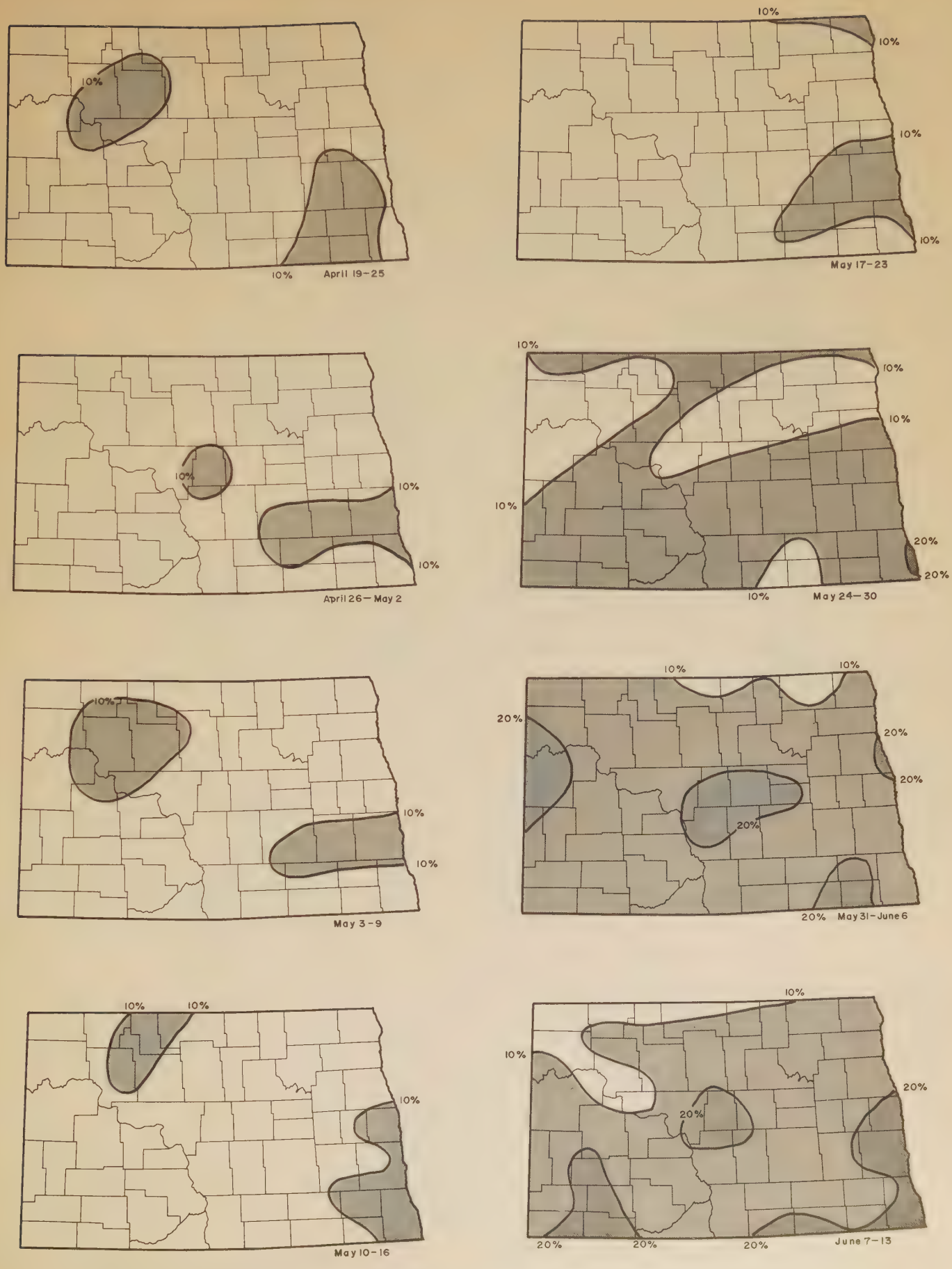
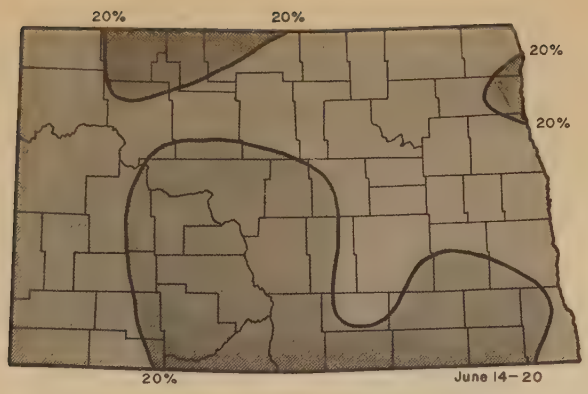
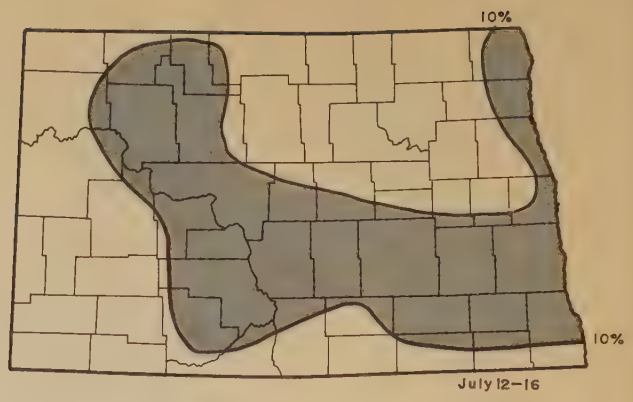
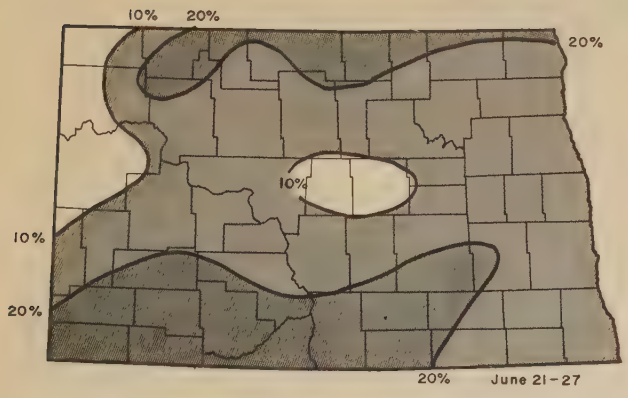
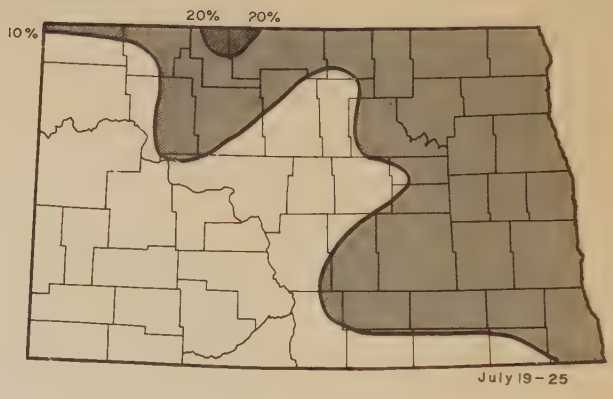


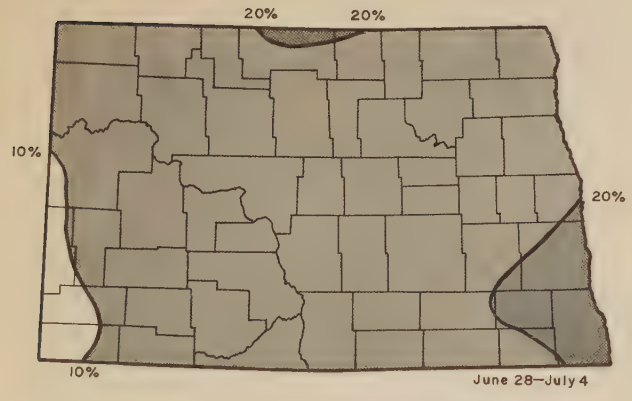
Figure 15. Chances of Receiving an Inch or More of Rain Per Day During the Growing Season.

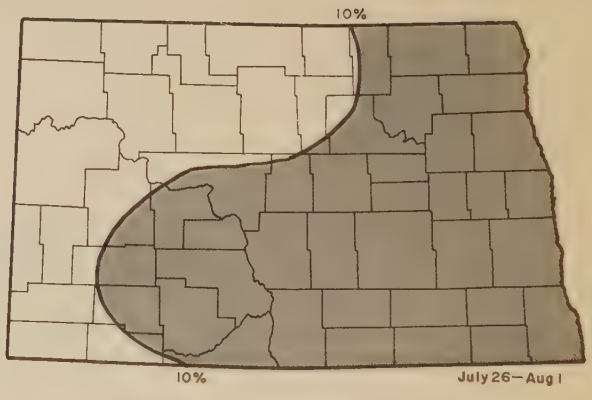


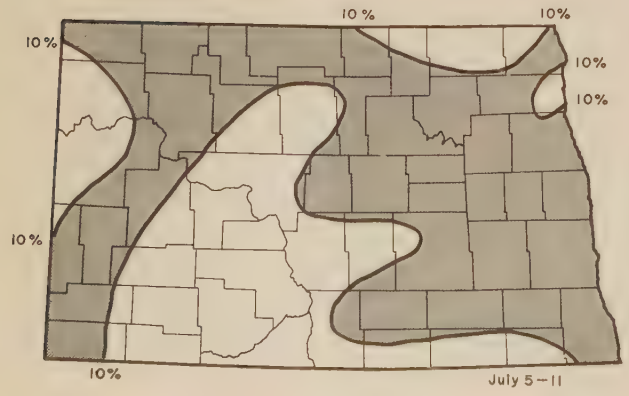












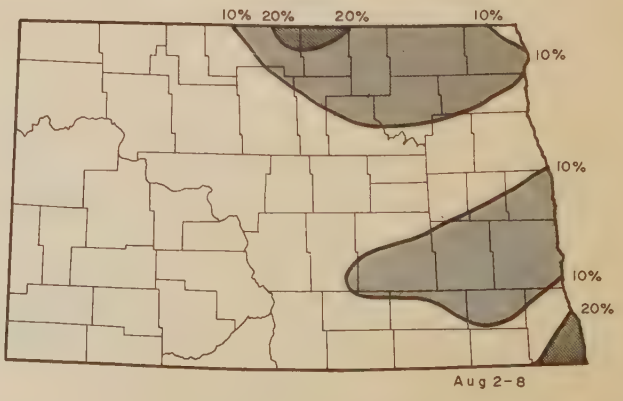


Figure 15. (Continued)

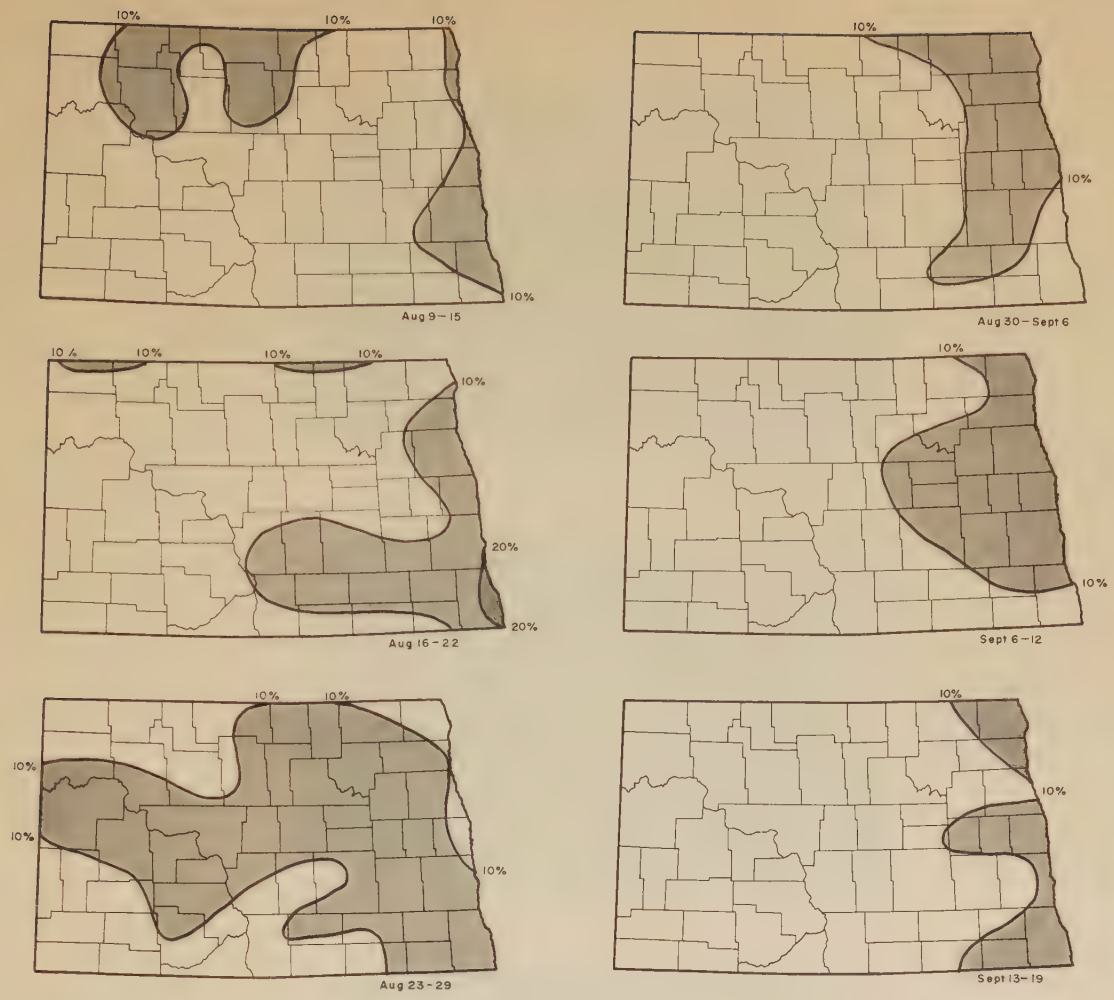


Figure 15. (Continued)

The Probabilities of Extreme Rainfall Occurrences

Runs of Days With Little or No Rain During the Growing Season

It is apparent in Figure 14 that the chances of receiving no rain at all in any week throughout the growing season are always less than 50 per cent across the state. These probabilities are lowest in about the first part of June and highest in mid-November and the rest of the winter.

Damaging "Downpours"

Excessive rainfall during the growing season can also be damaging to crops, considering associated problems like physical damage due to lodging, soil erosion and flooding. The occurrence of intense thundershowers resulting in an inch or more of precipitation per rainfall occurrence are very slim in North Dakota. This is illustrated in Figure 15, which shows the probabilities of getting an intense rainfall of an inch or more per day at least once in the specified week. The weeks selected were those where probabilities of more than 10 per cent exist at any point in the state. This period, when at least one location in the state may receive one inch or more of rain in at least one day of the week at least once in 10 years, extends from about mid-April to mid-September. During this period, the chances for these damaging downpours occurring at least once in a particular week range from 0 to 30 per cent. The higher probabilities (20 to 30 per cent) exist early in the season at the southeast portions of the state, spreading across the entire state until about late June when they become most probable.

Rainfall and Plant Disease

The incidence of plant disease is, among other factors, weather dependent. Plant pathogens, like most organisms, thrive best under certain environmental conditions. The persistence of a moist environment within plant canopies is known to be very favorable for plant disease development.

Hosford (11) stated that severe leaf spot damage has occurred on the foliage of wheat growing in North Dakota in wet years. He added that resistance in wheats to leaf spots is related to the duration of free moisture on the leaves. Conners (7), in a similar study in Canada, found that the number and size of leaf lesions caused by the fungal disease was related to the duration of available moisture from rain and dew and to the susceptibility of the host.

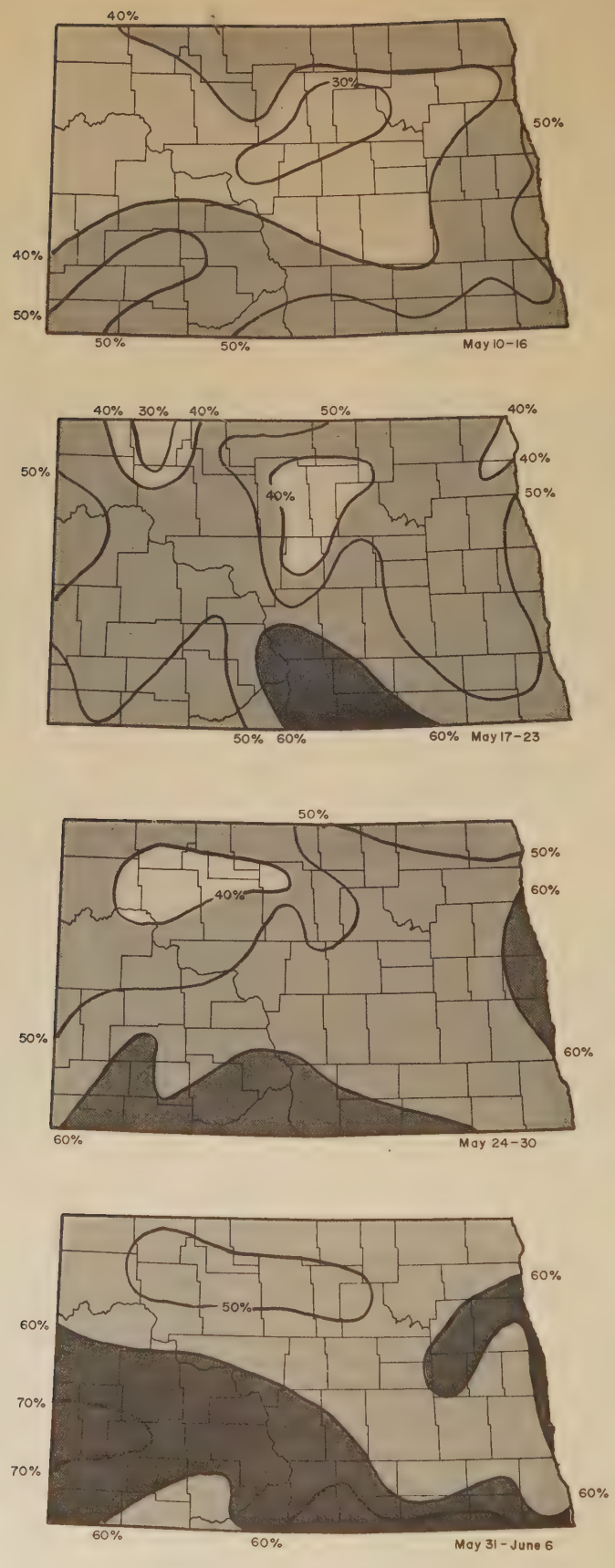
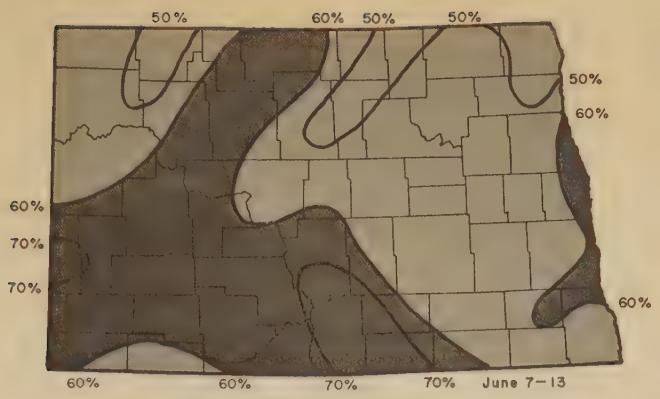
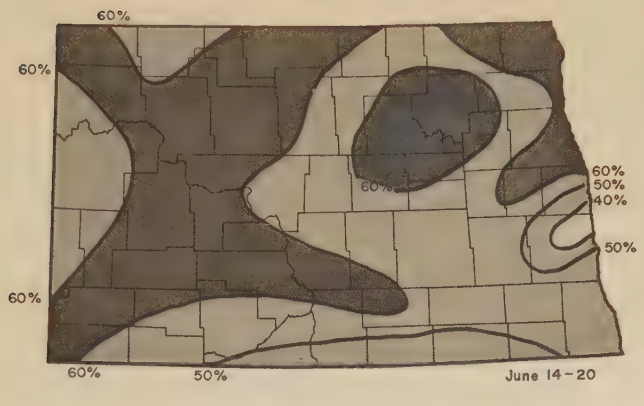
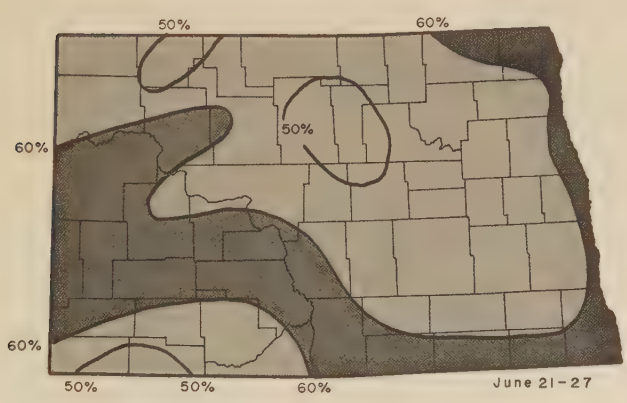


Figure 16. Likelihoods of at Least Two-Days-in-a-Row with Measurable Rainfall During the Growing-Season.







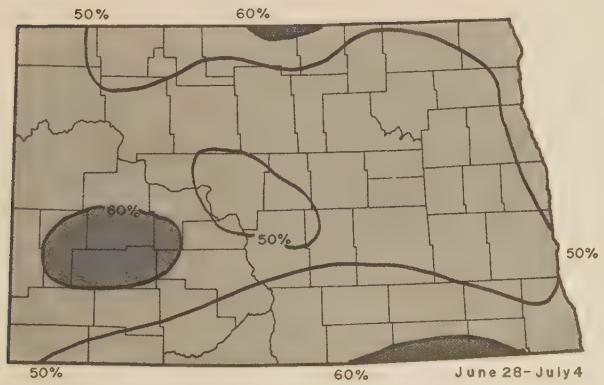


Figure 16. (Continued)

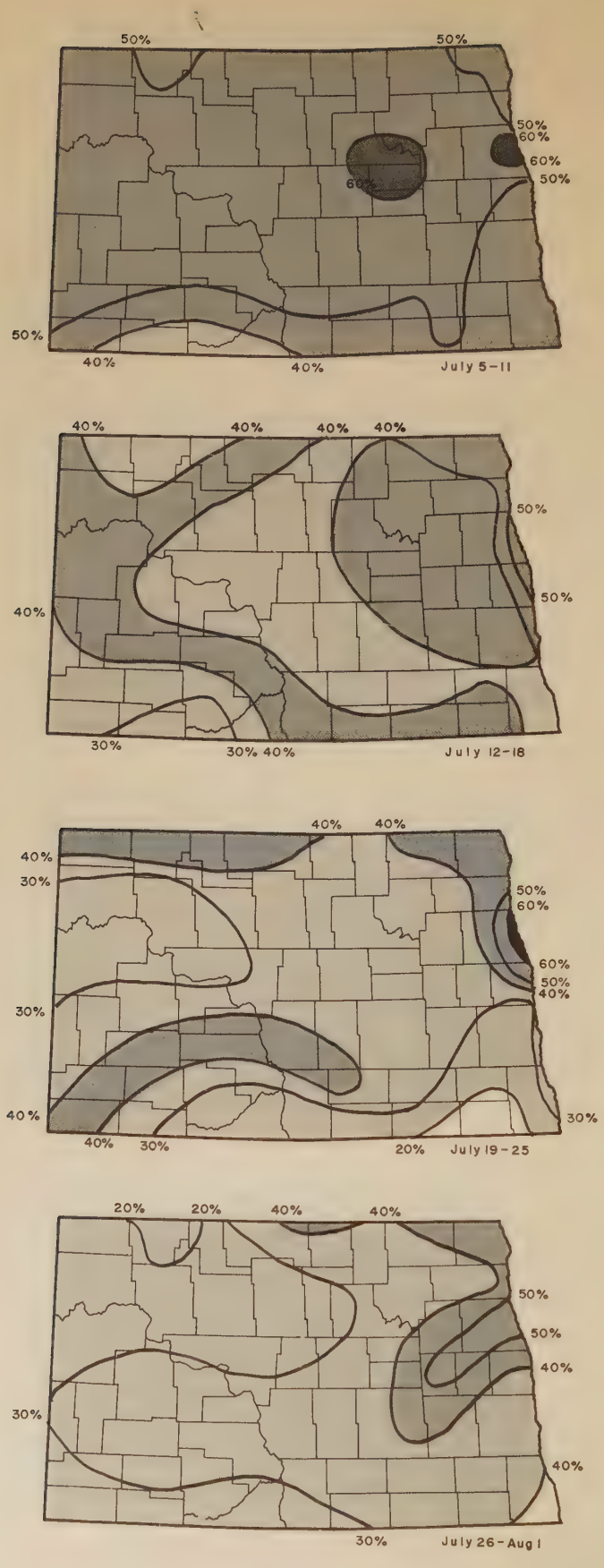


Figure 16. (Continued)

In Hosford's experiment (11), he concluded that Waldron wheat required 12 hours in mist for severe disease development, Chris wheat required 18 hours, and Leeds durum, 36 hours. He added that severity of the infection did not appear to increase when the plants were held for longer than 48 hours in the mist chamber. It is evident that the occurrence of periods of leaf wetting lasting from 6 to 48 hours is very significant in plant disease development.

Air temperature and humidity and dew duration are probably the atmospheric parameters that best describe the favorable or unfavorable conditions for plant pathogen infection of a plant canopy. Unfortunately, humidity is observed only once a day in very few selected climatic stations, and dew observations are not made at all in the National Weather Service network of first-order and cooperative climatic stations.

It is logical that the frequency of precipitation occurrences of any measurable amount can serve as an index of wetting in plant canopies during the growing season, since rainwater on leaf canopies can persist for some time after a period of rain and thus provide a favorable environment for plant disease organisms. The chances for at least one to three days of the weeks with some amount of precipitation, from early May through late July, are shown in Table 3 for six selected stations in the state. These occurrences might be isolated, but they could provide short periods of leaf canopy wetting.

Table 3. Likelihoods That at Least Three (3) Days of the Following Weeks Receive Some Amount of Rainfall

Weeks		EAST (per cent)			WEST (per cent)		
		Oakes	Fargo	Langdon	Dickinson	Minot	Williston
May	10-16	41	46	37	41	35	38
	17-23	41	44	33	46	43	36
	24-30	33	57	35	51	36	46
June	7-13	54	54	40	62	50	57
	14-20	51	42	50	56	54	59
	21-27	61	56	53	54	58	48
July	5-11	53	39	36	44	42	57
	12-18	39	42	30	40	32	36
	19-25	22	36	34	25	39	23

In May, there is about a 35 to 55 per cent chance of having at least three days of the week with some rain. These chances increase in June across the state up to about 60 per cent, decreasing again in July where chances are only 25 to 55 per cent across the state.

To get an idea of the likelihood for longer wetting periods during the summer and to describe the geographical distribution of these likelihoods, the maps of Figure 16 are presented. These maps show the probabilities of at least one occurrence of two days in a row in specified weeks with some amount of rainfall. Figure 16 suggests that some amount of rain for two days in a row are likely from about late May through June where the chances could be 50 per cent and more in portions of the state. These probabilities appear greater in the southeast in the early summer, progressing through June in the west-central and central portions of North Dakota.

WINTER PRECIPITATION

Jensen (14) stated that winter precipitation in North Dakota is nearly always in the form of snow. The water equivalents of average weekly precipitation amounts across the state are illustrated in Figure 17. As suggested by these maps, weekly precipitation in the winter seldom exceeds 0.2 of an inch per week, and when it does, it occurs only in early November in the Red River Valley. Winter precipitation is greater in the extreme eastern portions and least in the southern and central areas of North Dakota.

Precipitation Amounts for Soil Moisture Storage During the Winter

When one assumes that precipitation occurring during the period October through March is mostly in the form of snow, and that loss of water through evaporation and sublimation in the winter may be considered relatively small, winter precipitation is mostly stored in or on soil surfaces until spring thawing. It was pointed out earlier in this publication that this non-growing season precipitation provides an important source of soil water needed by crops in the spring. Jensen (14) calculated the average total precipitation across the state from October through March, and his illustration of the results is shown in Figure 18. Winter precipitation (October to March) ranges from about 4½ inches in the eastern and central portions of the state to about 3 inches in most of the western areas of North Dakota.

Snow Accumulation in North Dakota

Snowfall in North Dakota ranges from about 26 inches in the northwest to a little more than 38 inches per year in the northeasternmost portions of the state (Jensen, 14). As pointed out by Jensen (14), these amounts are considerably less than that of any state east of North Dakota bordering Canada and all states west of it. Deep snow accumulation is not normally common in the state, averaging only from about nine inches in the southwest to 15 inches in the northeast.

Extreme Snowfall Occurrences

Non-residents often are surprised to learn that heavy snowfall is not common in North Dakota. The series of maps of Figure 19 show the likelihood of at least one day per week when snowfall for 24 hours is greater than three inches. As shown, these

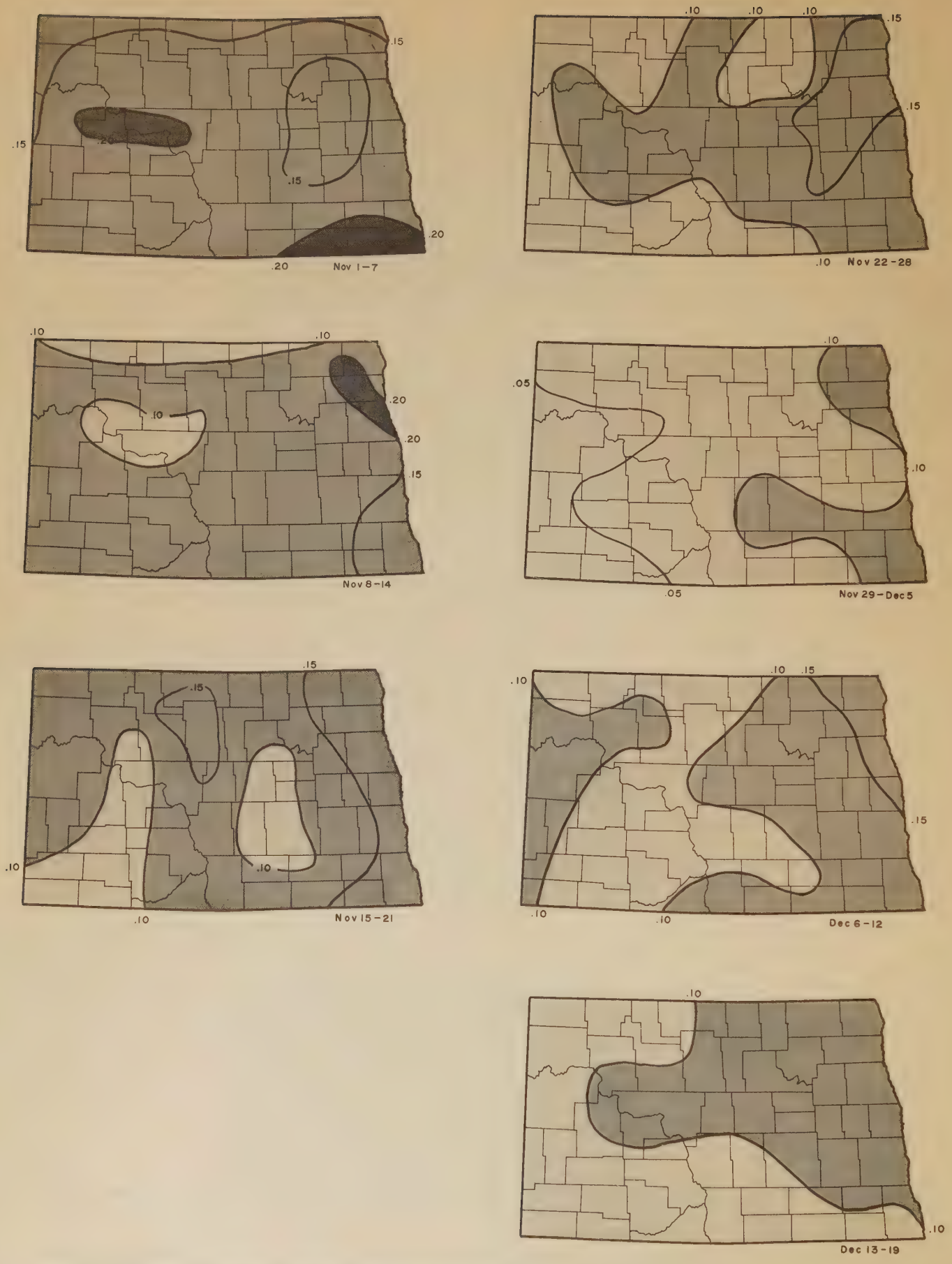
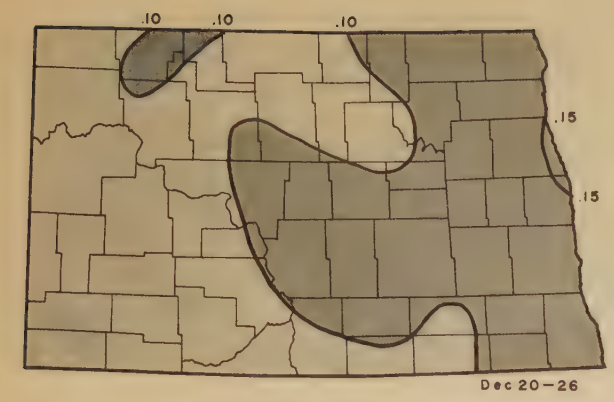
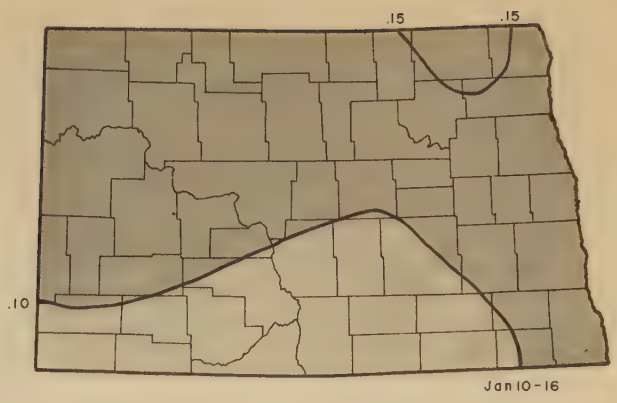
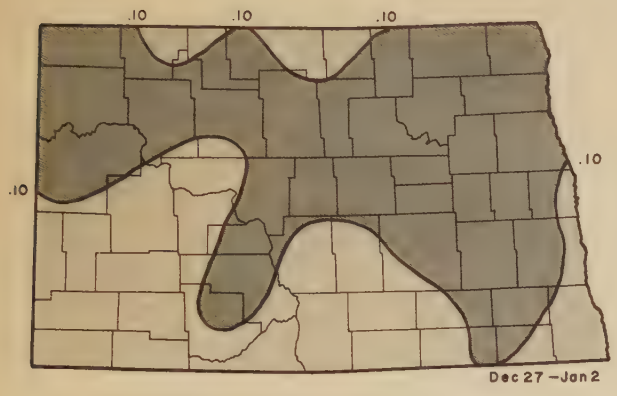
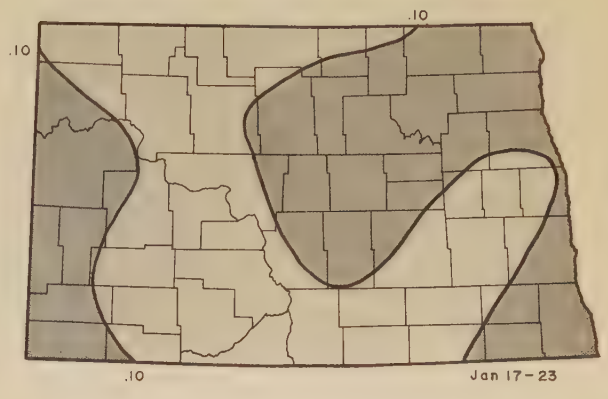


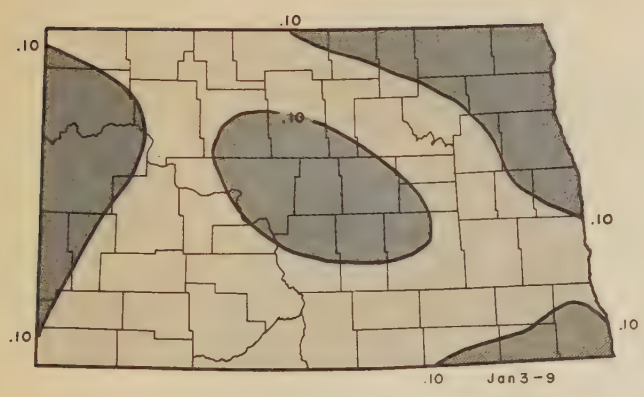
Figure 17. Water Equivalents of Average Weekly Winter Precipitation Across North Dakota.

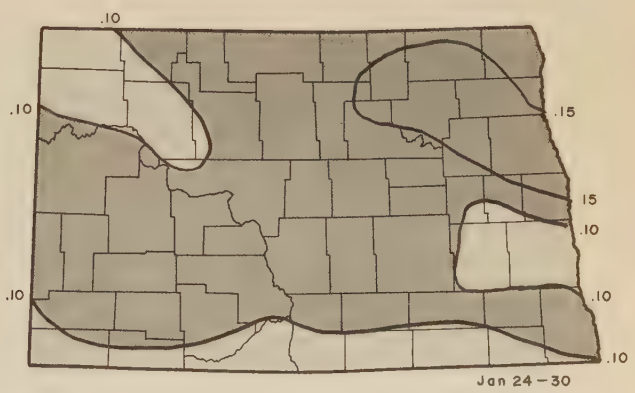












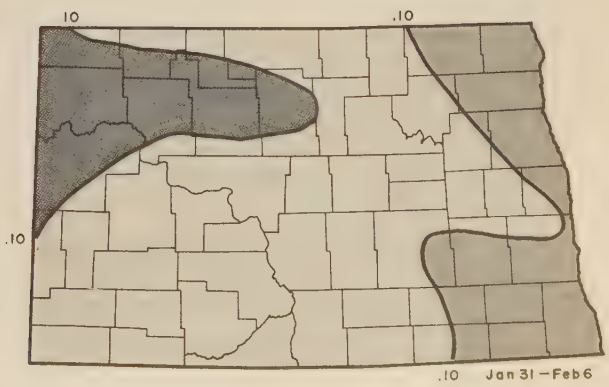
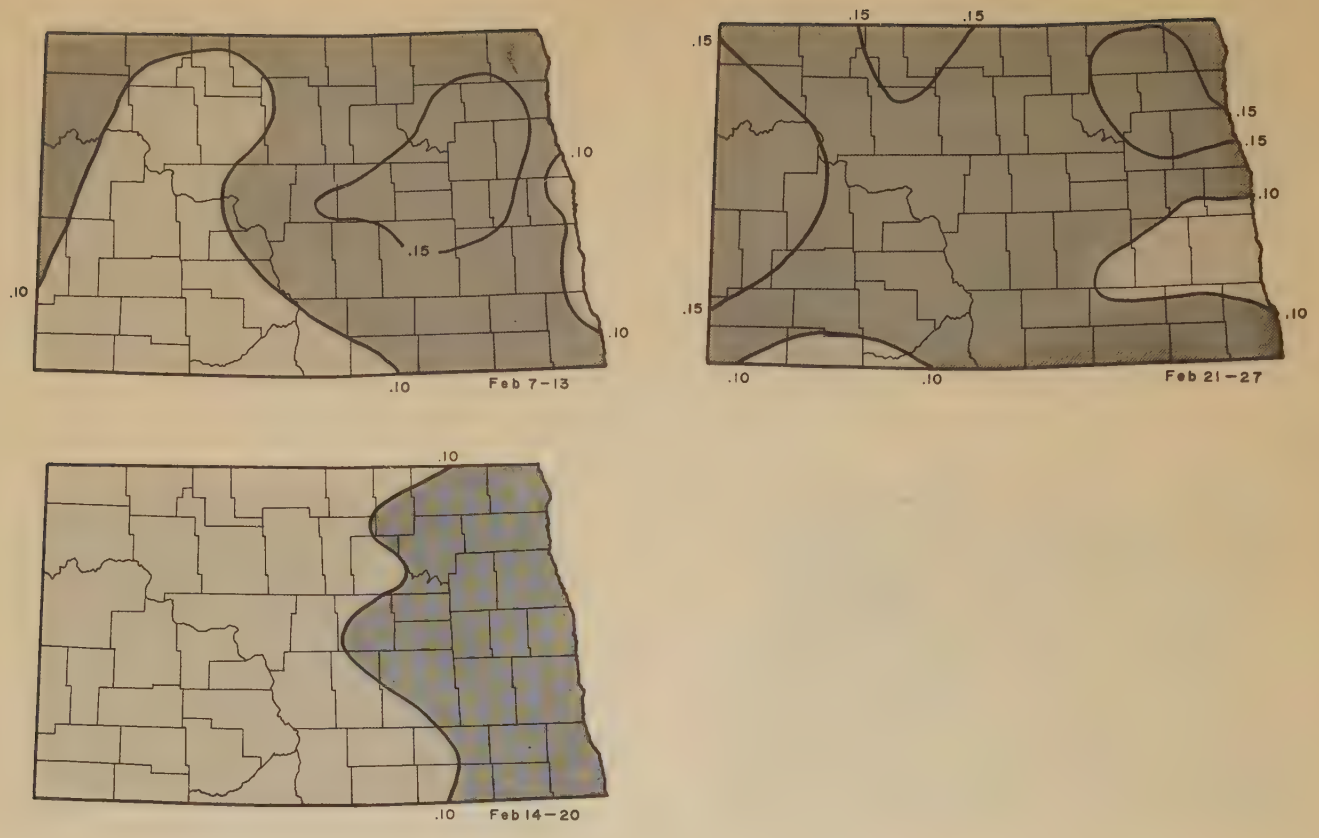


Figure 17. (Continued)



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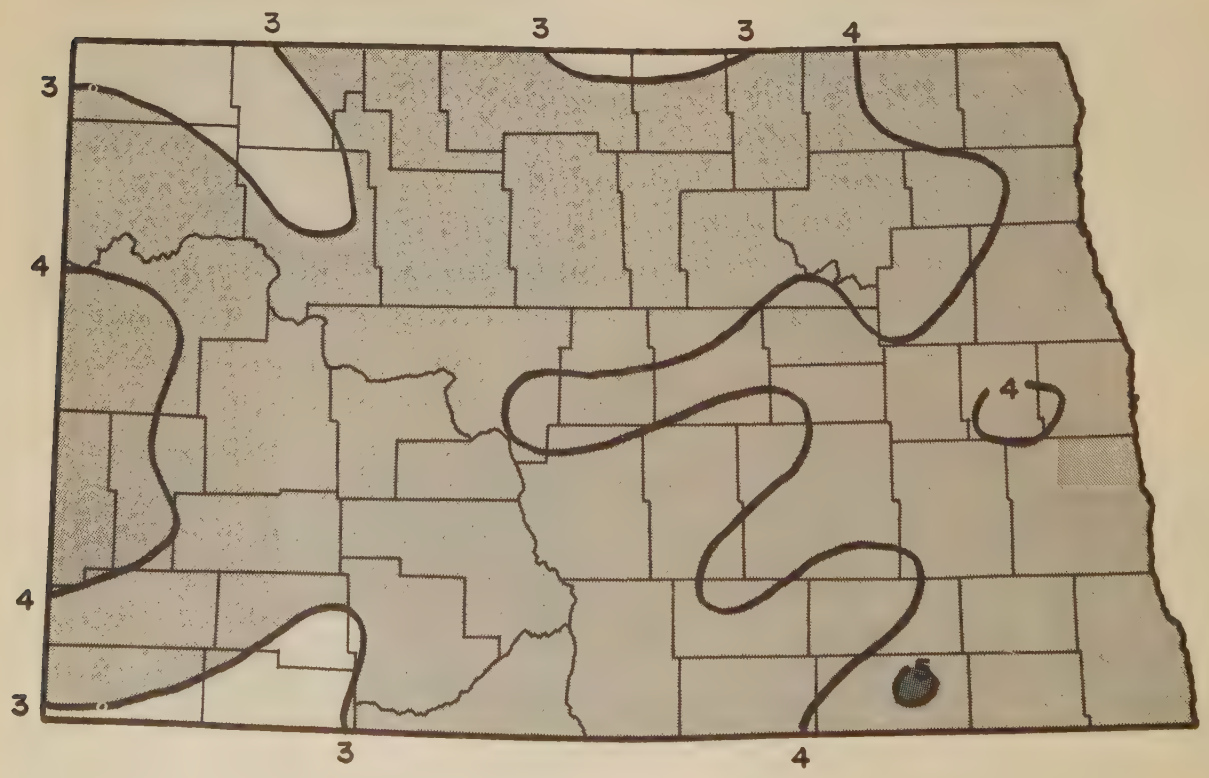


Figure 18. Average Total Winter Precipitation (melted water equivalents) in North Dakota.

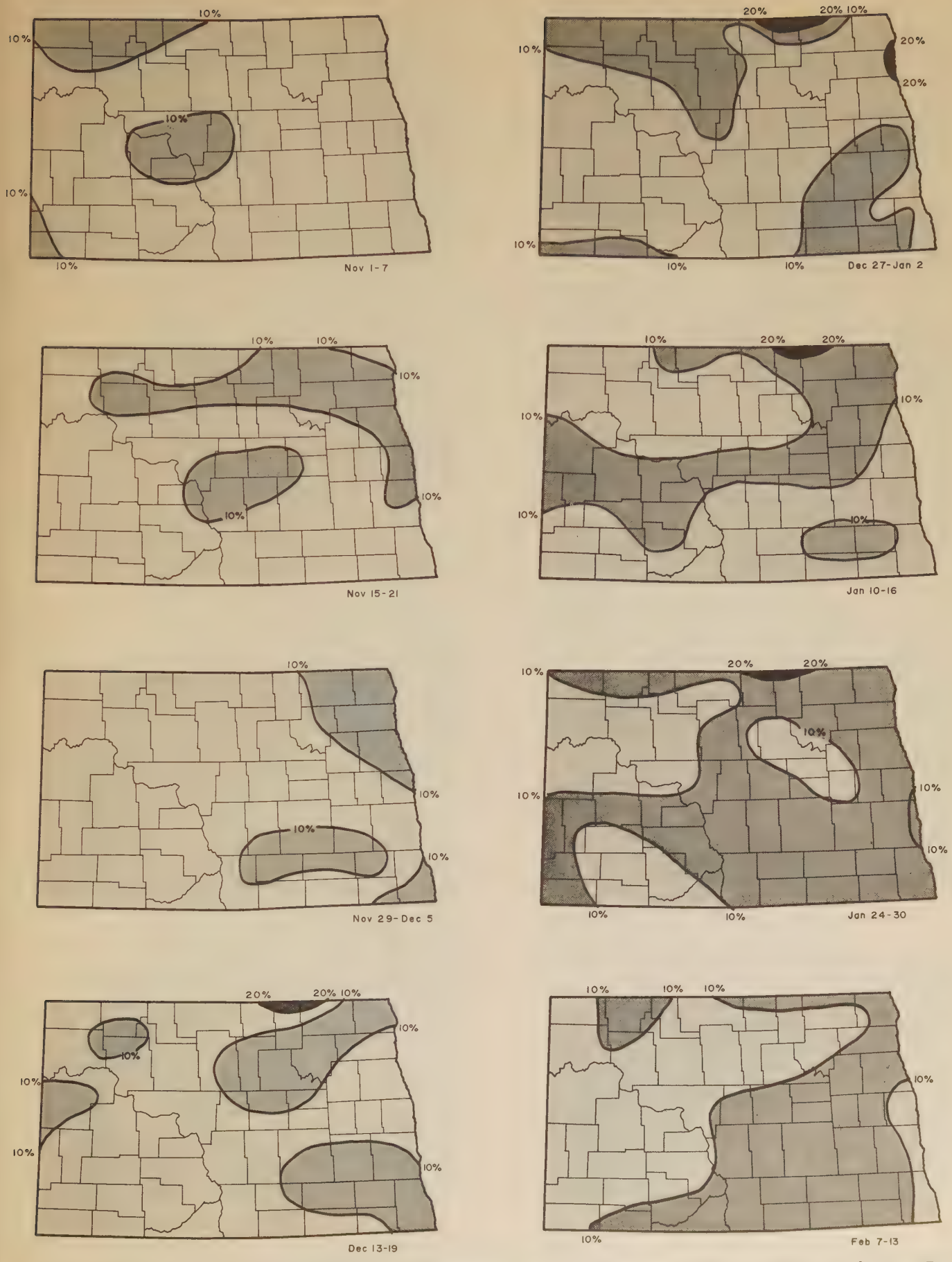


Figure 19. Probabilities of at Least One Day of the Week in Winter When Snowfall Exceeds Three Inches per Day.

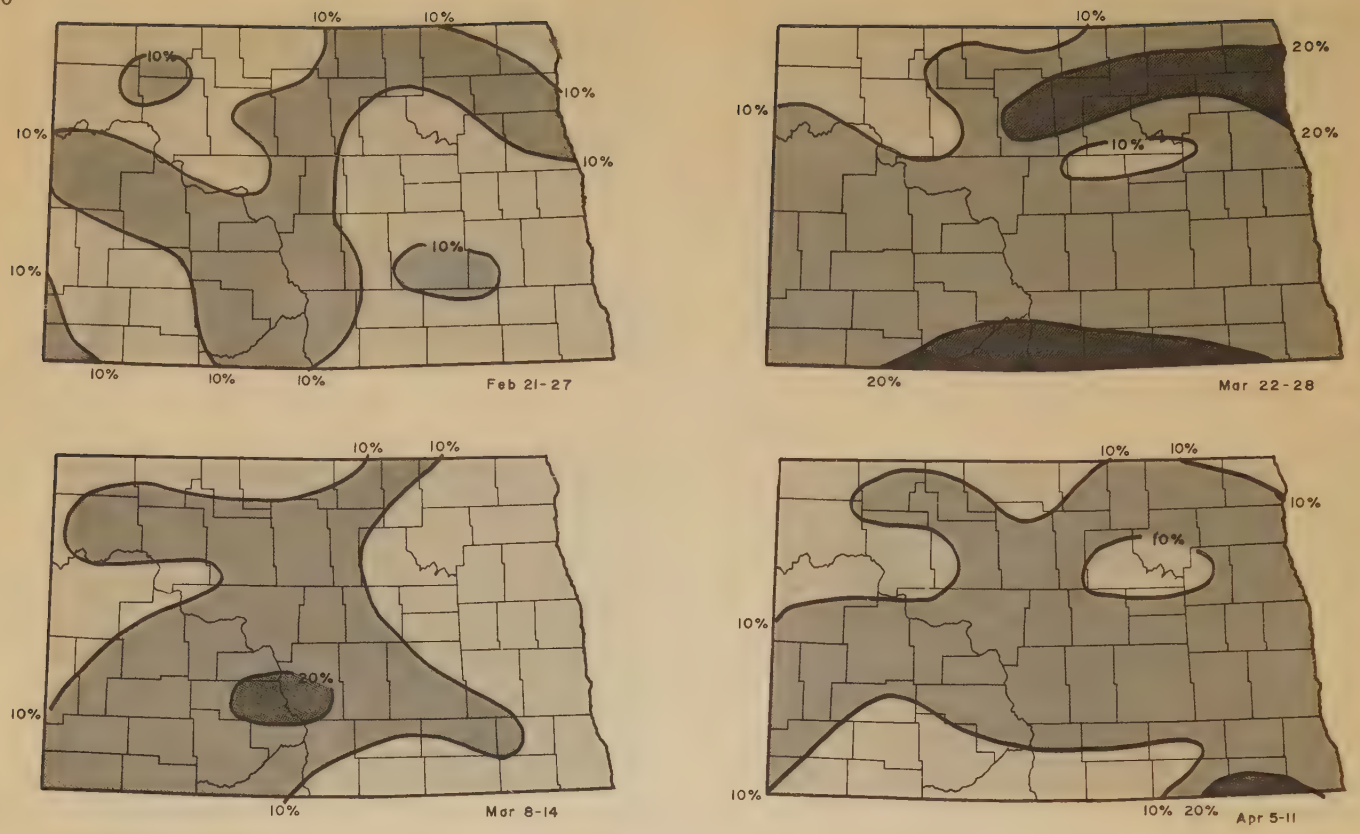
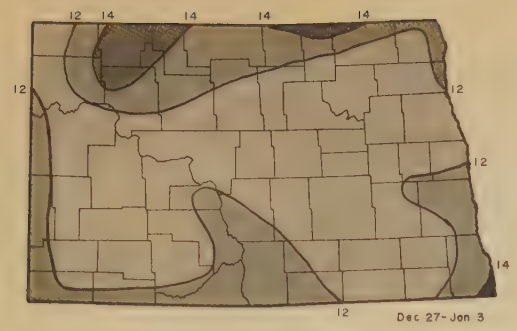
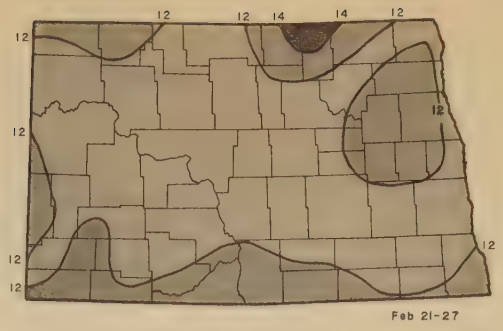
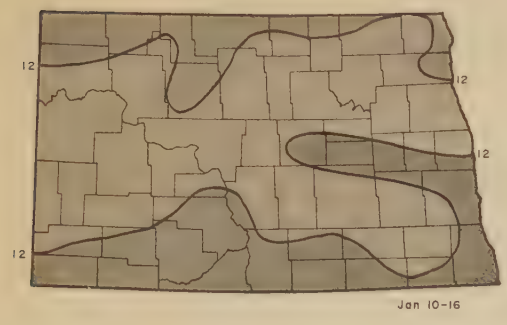


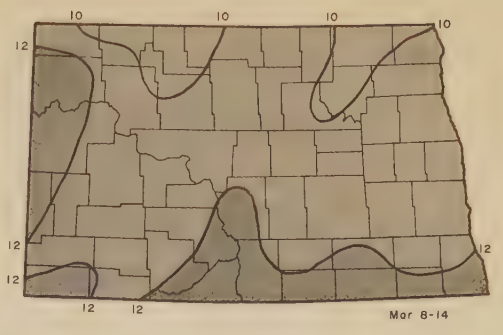
Figure 19. (Continued)

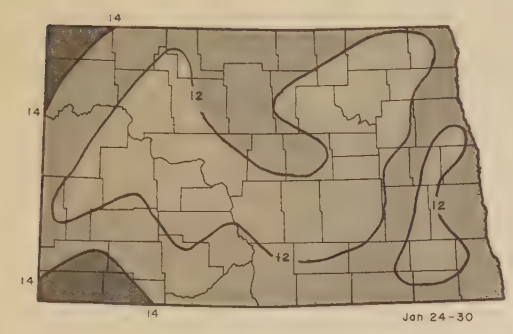
Figure 20. The Distribution of Snowdepth-to-Melted Water Equivalent Ratios across North Dakota.

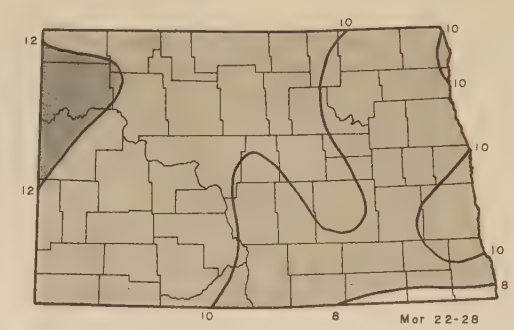


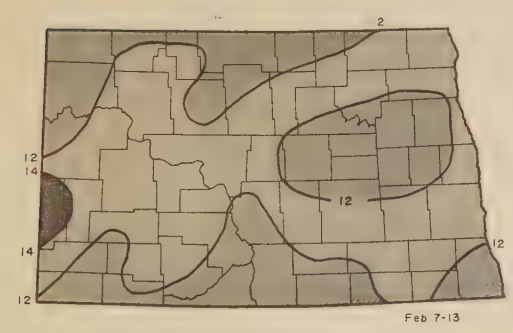


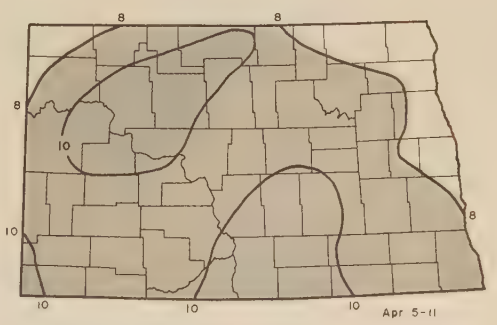












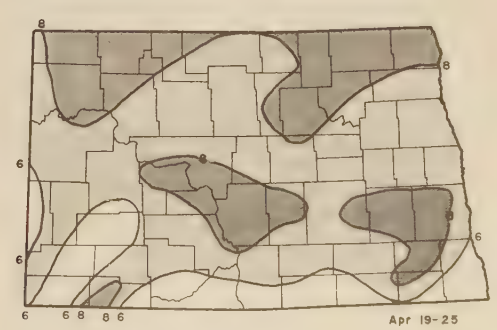


Figure 20. (Continued)

occurrences have a probability of 10 per cent or less in November across the entire state. In December and January, 24-hour totals of snowfall of three inches or more can occur up to about twice in 10 years, but only in small areas of northeastern North Dakota. During the remainder of the winter, snowfalls of greater than three inches per day are again less than 10 per cent probable.

Water Content of Snow

The National Weather Service measures both the actual thickness of snow cover after it falls and its equivalent water content, which is more accurately recorded as the standard measure of precipitation. It is understandable that snow cover measurement is less reliable than equivalent water content due to complicating effects of wind drifts. It is, however, a fair estimate for practical use by the public.

Snow at different times of the season and at different locations may either be drier or wetter than usual. To gain an insight into the relative wetness or dryness of snow in North Dakota, weekly snow depth measurements were compared with the actual melted water equivalent of the snow. The results are shown in Figure 20. The isolines on the maps represent the ratio of snow depth to the melted water equivalents.

In interpreting Figure 20, one should remember that the larger the numbers shown on the maps, the drier the snow. As an example, if one foot of snow falls which contains only one inch of water, the ratio would be 12/1 or 12:1. In Figure 20, this is represented as 12. In another case, if the foot of snow contained 1.2 inches of melted water instead of only one inch, the ratio would be 12/1.2 or 10:1 and is shown in the maps as simply 10.

These maps suggest that in North Dakota, amounts of snow required to produce an inch of water can range from six to 14 inches. Another way to look at it would be to say that an inch of fresh snowfall in the state can contain as little as 0.07 inch or as much as 0.17 inch of equivalent rain. Snowfall is apparently driest in the cold winter months of November through mid-March, when as much as 10 to 14 inches of snow is required to produce an inch of melted water. In late winter when temperatures become warmer, snow becomes wetter, particularly in late March and April. The maps also suggest that drier snowfall occurs in the more northern and western areas than in other locations of the state during most of the winter. The wetter snow generally falls in the southeast, southcentral and most notably in the central areas of North Dakota.

D. RAINFALL MODIFICATION

Changing the Weather: State of the Art

The great variability of climate over all scales of time in the history of the earth is well established. Climate has changed markedly in the past due to natural causes, and weather itself changes within a much shorter period of time as the year progresses and from one place on earth to another. Might man cause similar changes, even on lesser magnitudes, on weather and climate?

Magnitude of the Problem

When one considers meeting such weather hazards as severe storms by taking the offensive and trying to change their course or minimize their damaging effects, he must recognize the magnitude of energy involved in those weather systems. Deliberate weather modification cannot, at least in the foreseeable future, effect changes by matching the energy which drives the natural atmospheric processes in tornadoes, hurricanes or even thunderstorms. This is aptly illustrated when one considers, for example, that to match the energy of the air motion of a single, medium-sized thunderstorm would require all the electric power generated in the United States for almost one hour, and that is assuming that this total power could be concentrated in one particular area. This point is further illustrated by considering the fact that a medium-sized hurricane is driven by energy equivalent to the simultaneous explosion of 400 20-megaton bombs! It does not seem likely that man can use "brute force" to tame these violent storms.

A logical approach, however, is suggested by observing that most weather phenomena are triggered by some instabilities that set off the chain of events characteristic of the storm. Searching for an "Achilles heel," or a point of weakness, has been a popular approach in most weather modification attempts now being carried on. The technique is to trigger some internal instability within the storm to hopefully set off a predictable series of events leading to reducing its intensity.

Cloud Seeding for Additional Rain

There seems to be powerful motivation to produce more rain, or to redistribute the amount that now falls. Rainfall in many cases occurs in great amounts, often where and when it is a hazard and seldom where and when rains are critically needed. For this reason and because of the growing concern about a global water crisis, weather modification attempts seem to be centered toward artificially producing additional rain.

To understand the basic principle behind the scientific approach to rainmaking, the reader might refer to the brief discussion of the physical process of cloud formation and precipitation on pages one and two of this bulletin. Water vapor must first condense into clouds and the unique existence of both supercooled water droplets and ice crystals above the freezing level in a cloud is one requisite for the precipitation process to start. Clouds with sufficient moisture in them may exist above freezing levels. At these levels, the water droplets within the cloud are supercooled without freezing. It is common for liquid water drops to exist in clouds at temperatures as low as —20° C. It is, however, the formation of sufficient ice crystals that seems to inhibit precipitation formation in some clouds.

For pure water to become ice, the molecules must arrange themselves into a particular configuration, and such an arrangement arises by chance. The lower the temperature of the cloud the greater this chance becomes. An "ice embryo" forms when a number of molecules arrange themselves into the proper configuration. This embryo can grow and act as a nucleus to which other molecules can adhere to form ice crystals. In 1946, Vincent Shaeffer, then working as a laboratory technician with General Electric, discovered that he could induce ice crystal formation in a home freezer by sprinkling dry ice into the freezer. He did create a miniature snowstorm in the freezer when dry ice at a temperature of —78° C temporarily cooled the air to force the freezing of the super-cooled water droplets into ice crystals. It has since been demonstrated that this same phenomenon can be duplicated in actual clouds. Certain artificial nuclei such as silver iodide particles (which have an atomic arrangement very close to that of ice) have been found to be very effective in causing supercooled water droplets to freeze.

The "Unknowns" in Cloud Seeding

There still exists, however, much controversy on the effectiveness of operational cloud seeding to increase rainfall. Proving beyond reasonable doubt the effectiveness of cloud seeding in increasing rainfall requires complicated statistical analyses. This problem is magnified by the fact that, at the present time, it is not possible to precisely estimate how much rain will fall over a given area naturally, and how much more could be forced to fall if cloud seeding is effective.

Most meteorologists agree that seeding does increase precipitation under certain conditions. Some types of clouds behave erratically in response to seeding, and it appears that cloud seeding is most effective in stimulating precipitation from winter storms over mountains. While some studies suggest an increase of up to 40 per cent in rainfall amounts due to seeding, other studies report possible decrease in natural rainfall, especially in the larger storms (3, 6, 8). Nonetheless, most researchers agree that the current problem now is not whether rainfall can be increased by cloud seeding, but rather whether or not it is desirable and what operational approach is most effective.

In view of the ever-increasing public interest in the potential of rainfall modification, some scientists express concern about the growing evidence (9) that changes in rainfall have been observed on large non-target area from local single-cloud seeding in another area. More studies are necessary to assess the long term and even short term effects of rainfall modification. It is recognized that the exact chain of consequences that might follow cloud seeding operations cannot yet be predicted in advance.

REFERENCES

1. Barger, G. L. and H. C. S. Thom. 1949. *Evaluation of Drought Hazard.* Agron. Jour. 41:519-526.

2. Barger, G. L., R. H. Shaw and R. F. Dale. 1959. *Chances of Receiving Selected Amounts of Precipitation in Missouri.* N. C. Regional Tech. Committee Publication.

3. Battan, L. J. 1966. *Silver-iodide Seeding and Rainfall from Convective Clouds.* J. Appl. Meteor. 5:669-683.

4. Bauer, A. 1972. *Effect of Water Supply and Seasonal Distribution on Spring Wheat Yields.* No. Dak. Ag. Expt. Sta. Bul. 490.

5. Bennet, E. S., J. E. Newman, P. W. Dailey, Jr., E. Petzhold, and L. H. Smith. 1969. *Precipitation Probabilities in Weather Forecasts.* Purdue U. Coop. Ext. Service Bul. No. AY-174.

6. Braham, R. R., Jr. and J. A. Flueck. 1970. *Some Results of the Whitetop Experiment.* Preprints of Papers, Second Nat'l Conf. Weather Modification, Santa Barbara, Calif. Amer. Meteor. Soc. 176-179.

7. Conners, I. L. 1940. *Yellow Leaf Blotch.* 19th Annual Report of the Canada Plant Disease Survey. p. 12-14.

8. Decker, W. L., and P. T. Schickedanz, 1966. *The Evaluation of Rainfall Records from a Five-year Cloud Seeding Experiment in Missouri.* Proc. 5th Berkeley Symposium on Mathematical Statistics and Probability, Vol. 5 Univ. of Calif. Press, 55-63.

9. Dennis, A. S. 1972. *Conference Summary on the Third National Conference on Weather Modification.* Bul. of Amer. Meteor. Soc. 53, No. 9. p. 878-879.

10. Friendman, D. G. and B. E. Jones. 1957. *Estimation of Rainfall Probabilities.* Storrs. Agr. Expt. Sta. Bul. 332.

11. Hosford, R. M., Jr. 1971. *A Form of Pyrenophora Trichostoma Pathogenic to Wheat and Other Grasses.* Phytopathology 61:28-32.

12. Hughes, L. A. 1965. *On the Probability Forecasting of the Occurences of Precipitation.* U. S. Dept. of Commerce, ESSA, Weather Bureau. Tech. Note 20-CR-3.

13. Jensen, L. A. and H. R. Lund. 1967. *How Cereal Crops Grow.* Extension Bulletin No. 3. North Dakota State University, Fargo.

14. Jensen, R. E. 1972. *Climate of North Dakota.* North Dakota State University, Fargo, N. D.

15. Ramirez, J. M. 1972. *The Agroclimatology of North Dakota, Part I. Air Temperature and Growing Degree Days.* Extension Bulletin No. 15, North Dakota State University, Fargo.

16. Roberts, C. F., J. Porter and G. Cobb. 1967. *Report on the Forecast Performance of Selected Weather Bureau Offices for 1966-67.* U. S. Weather Bureau Tech. Memo. WBTM FCST-9

17. Thom, H. C. S. 1957. *A Statistical Method of Evaluating Augmentation of Precipitation by Cloud Seeding.* Tech Report. No. 1 in Vol. II of Final Rept. of Pres. Advisory Committee on Weather Control. Washington, D. C.

18. Thom, H. C. S. 1958. *A Note on the Gamma Distribution.* Monthly Weather Review 86:117-122.

This bulletin is the second in a four-part series of publications on the climate for agriculture in North Dakota. Included in this series are the following:

Part I. Air Temperature and Growing Degree Days
(Extension Bul. No. 15; published in June, 1972)

Part II. Precipitation: Forecast, Probabilities and Rainmaking
(Extension Bul. No. 16; this present publication)

Part III. Drought and Wet Spell Occurrences
(Extension Bul. No. 17; forthcoming)

Part IV. Severe Storms and Lesser Disturbances; Influence on Agricultural Production
(Extension Bul. No. 18; forthcoming)

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